Efficiency and Productivity Improvements at a Platinum Concentrator

Development of a Management Tool to Measure and Monitor OEE and Process Pain

Master of Science Thesis in Quality and Operations Management, Mechanical Engineering

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Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
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Parts of the comminution process at Mogalakwena North Concentrator, Limpopo, South Africa (Josefine Älmegran, 2012)

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ABSTRACT

The current low platinum price has put high pressure on the industry and forced companies to introduce cost cutting efforts as well as productivity increasing actions. Increasing the productivity can be done either by increasing the output or decreasing the amount of consumed resources. This project has focused on the latter. There are several productivity increasing methods, such as Total Productivity Maintenance (TPM) and Lean, to utilise. In the mining industry these methods have not been used to the same extent as in, for instance, the automobile industry to improve productivity. Existing research in mining mostly deals with the technical aspects of the process, such as optimising single units.

This project has three distinct phases and will use the incorporated tools of TPM and Lean to, firstly define a calculation model of equipment performance metrics for a single stream comminution process. Secondly, a tool to perform real time calculations of defined metrics will be developed. Thirdly, a method for using the tool output in the organisation in a value creating way, with primary focus on finding root-causes to productivity limiting issues, will be designed.

The project is a collaboration between Chalmers University of Technology, Gothenburg, Sweden, and the University of Cape Town, South Africa. The project sponsor is Anglo American Platinum and the plant where the project has been conducted is Mogalakwena North Concentrator (MNC), Limpopo, South Africa. MNC is ranked as the biggest single-stream platinum concentrator in South Africa and one of the largest facilities of its type in the world (Mining Weekly, 2008).

The Master's thesis writers have developed a method for calculating Overall Equipment Effectiveness (OEE) in a comminution process. The method incorporates a method to calculate quality, which is a parameter that has previously not been defined for a comminution process.

A method called Pain analysis has been developed by the Master's thesis writers to display duration and frequency of the reasons that cause the stops in the process. This new way of displaying stop data has been appreciated by its users and has received positive response from the organisation.

The developed Overall Productivity Tool (OPT) is at this stage a fully functional software used by MNC in daily work. The methods and day-to-day tools developed in this Master's thesis project will be incorporated in new software developed by Anglo American Platinum. The software is to be implemented throughout the organisation.

Answers to the research questions are provided at the end of the report as well as recommendations for the operations at Mogalakwena North Concentrator.

Keywords: Overall Equipment Effectiveness (OEE), productivity, efficiency, quality, availability, performance, overall utilization, process pain, platinum, concentrator, Overall Productivity Tool (OPT)

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CHAPTER ONE
INTRODUCTION

This chapter will introduce the Master's Thesis project by presenting a background of the problem, a company introduction, earlier efforts in the area, the project aim and finally the research questions

1.1 Project Introduction

The project is a collaboration between Chalmers University of Technology, Gothenburg, Sweden, and the University of Cape Town, South Africa. The sponsor of the project is Anglo American Platinum and the plant where the project has been conducted is Mogalakwena North Concentrator (MNC), Limpopo, South Africa. MNC is ranked as the largest single-stream platinum concentrator in South Africa and one of the largest facilities of its type in the world (Mining Weekly, 2008).

The examiner of this thesis is Prof. Magnus Evertsson (Chalmers University of Technology). Dr. Erik Hulthén (Chalmers University of Technology) and Dr. Aubrey Mainza (University of Cape Town) have acted as supervisors. The writers of this Master's thesis are B.Sc. Anton Kullh (Chalmers University of Technology) and B.Sc. Josefine Älmegran (Chalmers University of Technology).

This project was initiated by the supervisors who wanted to investigate how to increase productivity in a comminution process. The project scope has thereafter evolved throughout the project as the writers have gained more knowledge in the area of research. It is important to have a valid measure of productivity in order to be able to increase it and to be able to judge if your efforts are contributing to productivity improvements. The final scope is set as three distinct phases and can be viewed under 1.5 Project Scope.

1.2 Company Introduction

Anglo American Platinum Limited is a South African company which holds about 40% of the world's newly mined platinum, making them the world leading primary producer of platinum. The equivalent of refined platinum produced by their own mines amounted to about 44 tons in 2011.

To operate more effectively and efficiently Anglo Platinum recently accomplished a thorough reconstruction and they now operate nine individual mines around South Africa. One of them is Mogalakwena Mine, which is situated 30 kilometres northwest of Mokopane in the Limpopo province and operates under a mining right covering a total area of 137 square kilometres (Anglo American, 2012). Mogalakwena Mine provides ore to Mogalakwena South Concentrator (MSC) and Mogalakwena North Concentrator (MNC). MNC is ranked as the largest single-stream platinum concentrator in South Africa and one of the largest facilities of its type in the world and is the plant where this Master's thesis project was conducted (Mining Weekly, 2008).

1.3 Background

South Africa accounts for nearly 80% of the global platinum production, which makes the platinum price highly influenced by the economy of the country.

During the last five years there has been a large decrease in the platinum spot price. In March 2008 the price peaked at 2273 USD/oz t (Kitco, 2012), which can be compared to the spot price at the start of this project (mid-August 2012); 1485 USD/oz t (Kitco, 2012).

The price drop has several explanations. Firstly, the price spiked in 2008 due to a prospected supply shortage. Secondly, the sector has experienced wage inflation in excess of the general inflation. Thirdly, the strengthening of the rand has decreased the gap between dollar-denominated sales and rand-based costs. As a result of this, some high cost mines have had trouble running profitable operations during recent years. (Mail & Guardian, 2011)

This significant drop in price has put high pressure on the industry and forced companies to introduce cost cutting efforts as well as productivity increasing actions. This project will deal with the aspects of productivity.

An increase in productivity can gain several stakeholders and be profitable not only for the company itself, but also for the nearby communities, the region and the country.

1.4 Earlier Efforts In This Area

In the mining industry TPM and Lean have not been used to the same extent to improve productivity as in, for instance, the automobile industry. There is some research literature on productivity increasing efforts in comminution processes but it mostly deals with the technical aspects of the process, such as optimising a single unit, i.e. a ball mill. This approach can result in an unintended sub-optimisation instead of an optimisation of the entire process chain. The research has a gap concerning the usage of the above mentioned methodologies to improve the total productivity of the comminution process. Therefore, this thesis aims to help fill the gap and explain how to work with productivity increasing efforts throughout the entire process, instead of only in single units.

1.5 Project Scope

To increase productivity, the process needs to be completely comprehended and controlled. It is highly important to have a valid and accurate method of calculating equipment performance metrics, so that it can be monitored. Further, it will allow for the results of performed productivity increasing actions to be analysed and evaluated. This is in agreement with the author of the book *TPM Vägen till ständiga förbättringar* Örjan Ljungberg:

"*What you do not measure, you cannot control and what you cannot control, you cannot improve.*" (Ljungberg, 2000 p.37)

The methods TPM and Lean and their incorporated tools will found a basis for this Master's thesis project, which is divided into three distinct phases. Firstly, a calculation model of equipment performance metrics for a single stream comminution process will be defined. This calculation model will be aligned with the Anglo American Equipment Performance Metrics Standard and fully functional for a single-stream comminution process. Secondly, a tool to perform real-time calculations of the defined metrics will be developed. To achieve this, user friendly software which automatically computes the defined equipment performance metrics for the equipment included in the project will be developed. Thirdly, a method will be designed for using the tool output in the organisation in a value creating way. The primary focus will be on designing a method for finding root-causes to productivity limiting issues.

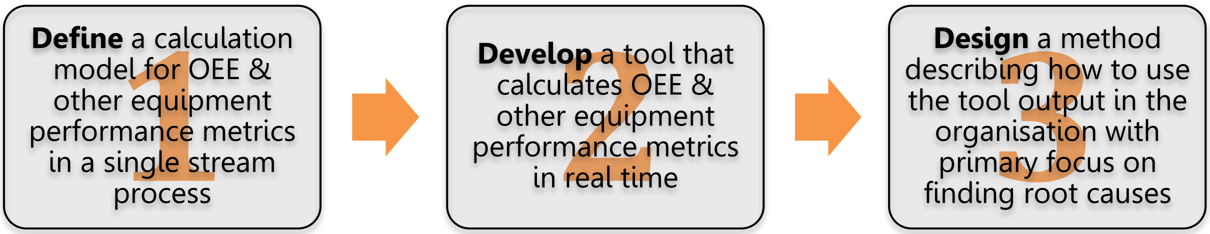


Figure 1 – The three phases of this Master's thesis project

1.6 Research Questions

The following research questions have been formulated for this Master's thesis. The research questions cover the areas of Overall Equipment Effectiveness (OEE), Performance indicators, productivity and SHE (Safety, Hygiene, Environment).

1. How can a method be developed to define and rank process units critical to productivity in a comminution process?

2. How should OEE numbers be calculated in a single-stream comminution process?

3. Which factors in the process chain are more critical to productivity – according to the OEE philosophy?

4. How can OEE be used as a performance measure of equipment and process performance?

5. How can OEE help to improve SHE (Safety, Hygiene, Environment)?

6. How can measuring OEE help to improve productivity?

1.7 Delimitations

To fulfil the purpose of this Master's thesis, the project concentrated on the initial part of the comminution circuit of a minerals processing plant, which at MNC includes the primary gyratory crushing, the secondary crushing, HPGR-crushing, classifiers, feeders, and conveyors.

The research was limited to this area for two reasons; it is a good idea to start the implementation in a small scale and it would have been too time consuming for the Master's thesis to include a larger section of the plant.

The decision to limit the project to a sub-set of the plant is supported by Idhammar (2010) who argues that implementing OEE in a part of the plant will facilitate an implementation throughout the plant at a later stage. Idhammar also states that an early pilot can eliminate issues and provide useful training and experience for staff members.

The developed tool will be fully functional, however not completely integrated into the Scada and PI-system at the plant.

CHAPTER TWO
THEORETICAL FRAMEWORK

This chapter will present the theoretical framework used for the Master's thesis project. The theoretical framework shall act to facilitate understanding for readers with no or little former experience of the industry and the methodologies used in the project. However, the targeted readers of the report are assumed to already possess a basic knowledge in the area. Some basic definitions are therefore left out.

2.1 PRODUCTIVITY

A general definition is that productivity is the amount of output per unit of consumed resources or total costs incurred. Thus, productivity is defined as how efficiently the resources are being utilised in the production of goods or services. Increasing the productivity can hence be done by increasing the output, in terms of volume and quality, or decreasing the amount of consumed resources with a constant or increased output. (Prokopenko, 1992)

$$Productivity = \frac{Output}{Input} \qquad \text{Equation 1}$$

The essence of productivity improvement is working more intelligently, not working harder. There are several methods to help increase productivity. Two of the most well-known are Total Productivity Maintenance (TPM) and Lean. These methods, and some of their incorporated tools, will be described in more detail in the following sections.

2.2 TOTAL PRODUCTIVE MAINTENANCE (TPM)

Total Productive Maintenance (TPM) was first coined in Japan in the beginning of the nineteen seventies as a way of increasing the availability of machines and equipment by better utilising the maintenance resources. Simply put, it is about keeping machines and equipment in good condition without interfering with daily production. The methodology was created in order to support the Japanese effort to implement Lean in most of their industries. The fundamental idea of TPM is to involve the operators in the maintenance and make sure that they conduct most of the day-to-day activities instead of having the maintenance team do everything (Nakajima, 1989). Ahuja (2011) recognises that for a long time companies have seen maintenance as a static support activity instead of as a key component for revenue generation, which he claims it is. TPM demands collaboration between all functions in an organisation even though the most extensive is found between production and maintenance where the greatest synergies can be created. TPM is aimed at changing peoples' mind-set towards maintenance rather than providing a perfect tool that will solve all problems (Ahuja, 2011). According to Smith and Hawkins (2004) the primary focus of TPM should be to reduce and eliminate the effectiveness losses, since this is where the biggest gains can be achieved.

2.3 OVERALL EQUIPMENT EFFECTIVENESS (OEE)

There are many ways of measuring how well-functioning a certain unit is. One of the most common methods in the industry is to use availability as a metric. Other common methods are MWT (Mean Waiting Time), MTTR (Mean Time To Repair) and MTBF (Mean Time Between Failure). However, these parameters, and many other common parameters, do not give a comprehensive view of units and equipment if displayed alone. Included in TPM, there is a metric called OEE (Overall Equipment Effectiveness), which gives a more inclusive view of the value added by the unit, compared to other metrics. (Ljungberg, 2000)

It is important to identify the factors that limit the process from receiving higher

$$OEE = Availability \ x \ Performance \ x \ Quality$$ Equation 2

$$Availability = \frac{Gross\ Operating\ Time}{Planned\ Production\ Time} = \frac{(Planned\ Production\ Time - Unplanned\ Downtime)}{Planned\ Production\ Time}$$ Equation 3

$$Performance = \frac{Net\ Operating\ Time}{Gross\ Operating\ Time} = \frac{Ideal\ Cycle\ Time}{\frac{Operating\ Time}{Total\ Pieces}}$$ Equation 4

$$Quality = \frac{Valuable\ Operating\ Time}{Net\ Operating\ Time} = \frac{Good\ Pieces}{Total\ Pieces}$$ Equation 5

effectiveness and to understand how the process is performing. OEE is a method that can help to do this by giving a better understanding of how well a process is performing and by identifying what the limiting factors are. (Hansen, 2001)

An OEE number of 100% corresponds to a unit which is performing at its maximum capacity – always running, always at the optimal speed and producing perfect quality.

It is essential to note that OEE is more than just one number; it is, in total, four, which are all individually useful. The OEE measurement combines the availability of the machine, the performance rate and the quality rate in one equation (M. Maran, et al., 2012)

2.3.1 General OEE Definition

There is no established standard for how to calculate OEE for a single stream comminution process. A version frequently used in the manufacturing industry, derived from (Nakajima, 1989), is presented in Equation 2, and explained in more detail in Equation 3, 4, 5 and Figure 2.

Availability is the ratio between Gross Operating Time and Planned Production Time, where Gross Operating Time is Planned Production Time minus Unplanned Downtime. For definitions of parameters, see Figure 2.

Performance is the ratio between Net Operating Time and Gross Operating Time, where Net Operating Time is Gross Operating Time minus Speed Losses, or the ratio between the actual speed and nominal, budgeted, or target cycle time.

Quality is the ratio between Valuable Operating Time and Quality Losses, where Valuable Operating Time is Net Operating Time minus Quality Losses, or the ratio between Good Pieces and Total Pieces. The OEE calculation parameters are described in Figure 2.

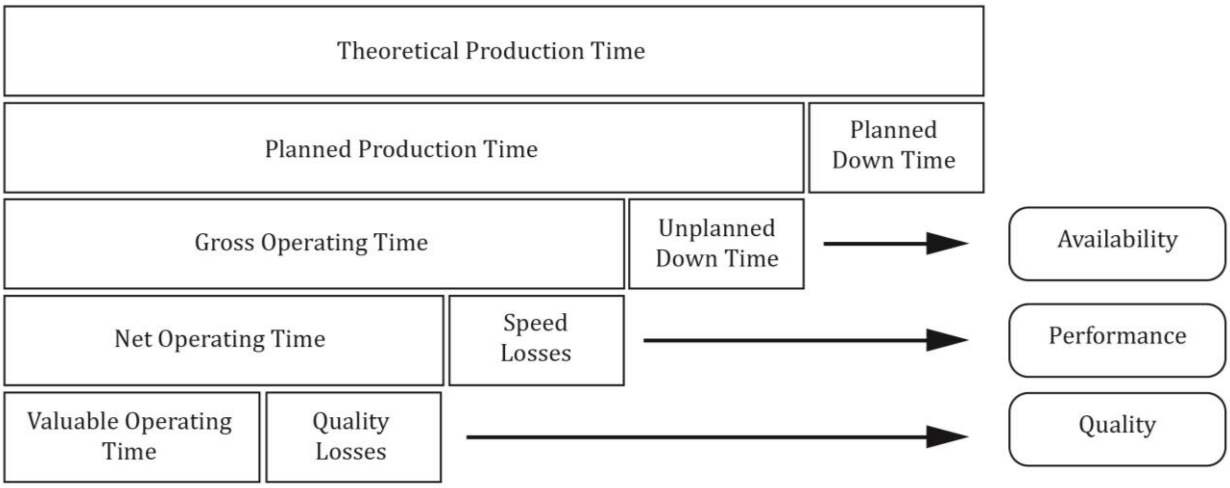


Figure: Freely after *Method and a system for improving the operability of a production plant*

Figure 2 – Definitions of the general OEE parameters

2.3.2 Anglo American Equipment Performance Metrics OEE Definition

The Anglo American Equipment Performance Metrics (a company internal standard) offers another way of calculating the OEE, which will be presented in this section.

The metric corresponding to the general OEE calculation's availability is titled Overall Utilisation (see Equation 6). This represents the ratio between Primary production (P200) time and Total time (T000), where Primary production is defined as "Time equipment is utilised for production" and Total time is defined as "The total possible hours available". (Anglo American Equipment Performance Metrics, 2012) For definitions of parameters, see Figure 3.

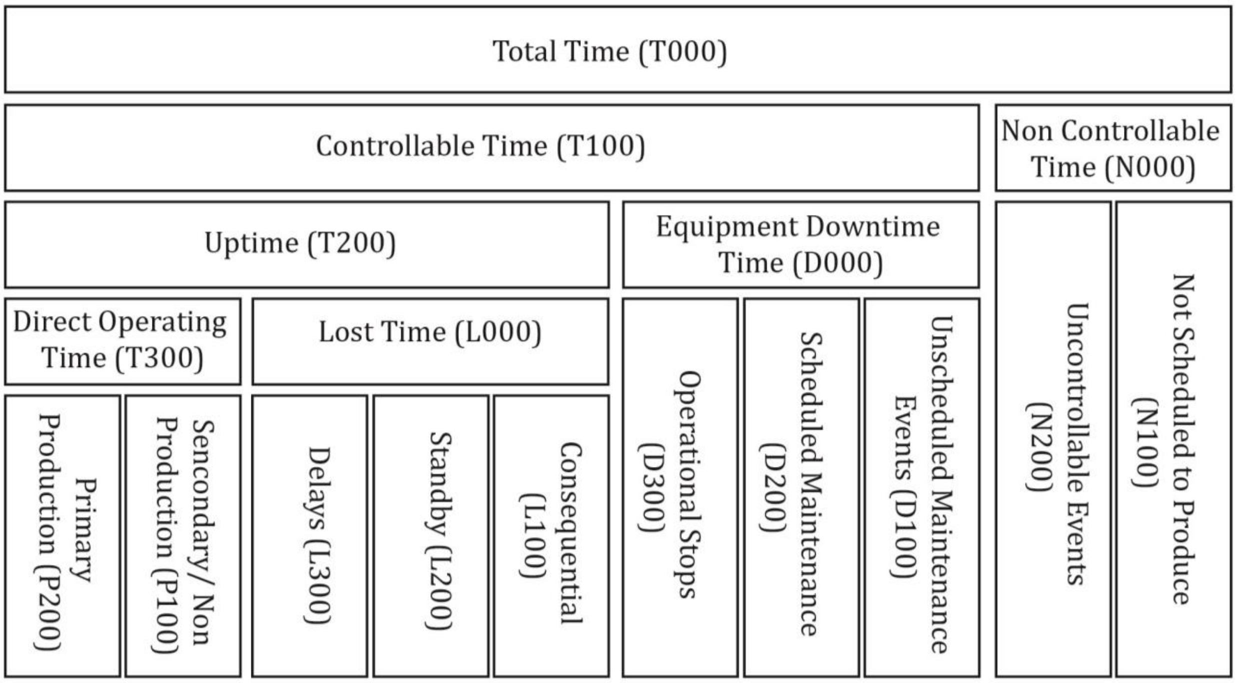


Figure: Freely after Anglo American Equipment Performance Metrics Time Model

Figure 3 – Time definitions by Anglo American Equipment Performance Metrics

The Performance metric (see Equation 7) is stated as "The portion of the OEE Metric which represents the production rate at which the operation runs as a percentage of its targeted rate". It is calculated as the ratio between Actual Production Rate and Target Production Rate, where Actual Production Rate is the ratio between Actual Production Achieved and Primary Production (P200), whereas the Target Production Rate is defined as an input. (Anglo American Equipment Performance Metrics, 2012)

The Quality is stated as "The portion of the OEE Metric which represents the Quality achieved at an operation as a percentage of its targeted Quality" and is calculated as the ratio between Actual Quality and Target Quality (see Equation 8). Both the numerator and the denominator are stated as inputs and no calculation method for them is provided in the Anglo American Equipment Performance Metrics. (Anglo American Equipment Performance Metrics, 2012)

2.3.3 OEE Benchmark

According to M. Lesshammar (1999) most equipment's OEE ranges from 40-60 %, whereas the world-class level is said to be 85 %. Smith and Hawkins (2004) have defined the world-class level at 85 % and it is composed of an Availability of 90%, Performance of 95% and Quality of 99%, which creates Equation 9.

According to Hansen (2001) very few companies calculate OEE or use it to maintain and set new priorities. He has defined different levels of OEE for companies to aim for, which can be described as follows:

- < 65 % Unacceptable. Money is constantly lost. Take action!
- 65-75 % OK, only if improving trends can be shown over a quarterly basis.
- 75-85 % Pretty good. But keep working towards the world-class level.

According to Hansen (2001) a batch type process should have a world-class OEE of >85 %, for continuous discrete processes the OEE value should be >90 % and for continuous on stream processes the OEE value should be 95 % or better.

2.3.4 OEE Economics

It is often hard to measure the financial benefits of proposed improvement projects and it is easy to oversee important projects and instead prioritise average projects. Bottlenecks are what prevent a process

$$Overall\ Utilisation = \frac{Primary\ Production\ (P200)}{Total\ time\ (T000)} \quad \text{Equation 6}$$

$$Performance = \frac{Actual\ Production\ Rate}{Target\ Production\ Rate} = \frac{Actual\ Production\ Achieved\ /\ Primary\ Production}{Target\ Production\ Rate} \quad \text{Equation 7}$$

$$Quality = \frac{Actual\ Quality}{Target\ Quality} \quad \text{Equation 8}$$

$$90\,\%\,(Equipment\ Availability)\ x\ 95\,\%\,(Performance\ Efficiency)\ x\ 99\,\%\,(Rate\ of\ Quality) = 84.6\,\%\ OEE \quad \text{Equation 9}$$

throughput and limits a plant from becoming effective; therefore, bottlenecks should be the first place where OEE is applied. In order to prioritise the OEE improvement projects relative to the average ones, it is important to be able to show the financial gains. (Hansen, 2001)

Hansen (2001) has shown that there is a link between OEE and critical financial ratios and that a company that understands and applies OEE improvement projects will harvest dividends year after year, since OEE improvement projects work to eliminate the root causes of problems.

According to Hansen (2001) a 10 % increase of OEE from 60 % to 66 % will give:

- 21 % increase of Return on assets (ROA)
- 10 % increase of capacity
- 21 % improvement of the operating income

He also states that starting on a low OEE, rather than on a high OEE, makes it easier to find opportunities to improve.

Ahlmann (2002) discusses the financial implications of an increased OEE from 60 % to 80 % in Swedish industry and argues that it shows a 20 % economic improvement.

2.4 CONTINUOUS IMPROVEMENT – KAIZEN (改善)

The term *kaizen*, in Japanese, literally means change (*kai*) for the better (*zen*). Kaizen is defined by Oxford Dictionaries as:

"*a Japanese business philosophy of continuous improvement of working practices, personal efficiency, etc..*"

Continuous improvement is the process of making incremental improvements, no matter how small, to achieve the lean goal of eliminating all waste that does not add any value but only adds cost. Kaizen teaches employees skills to work more effectively in smaller groups, solving problems, documenting and improving processes, collecting and analysing data, and also to self-manage within the peer group. (Liker and Convis, 2012)

The concepts of Kaizen started in the early days of Toyota and included the now famous concepts of just-in-time (JIT), process flow and quality improvements.

Kaizen can be divided into six main steps which became the basis for the Toyota Kaizen course developed by the company in the 1970's. (Kato and Smalley, 2011)

1. Discover Improvement Potential
2. Analyse the Current Methods
3. Generate Original Ideas
4. Develop an Implementation Plan
5. Implement the Plan
6. Evaluate the New Method

It has been understood that, in realtity, continuous improvements are impossible since some parts of the process sometimes need to be operated in the same way as the day before. Everything cannot be changed to the better every day. Continuous improvement is a vision, a dream, which no company can totally master. (Liker and Franz, 2011)

2.4.1 THE FIVE WHYS – 5 WHYS

One root-cause finding technique included in the kaizen methodology is the *5 WHYs*. It implies to ask why a problem exists five times, going to a deeper level with each why until the root cause of the problem is found. The user of the technique should take countermeasures at the deepest level feasible of cause and at the level that will prevent reoccurrence of the problem. (Liker and Convis, 2012)

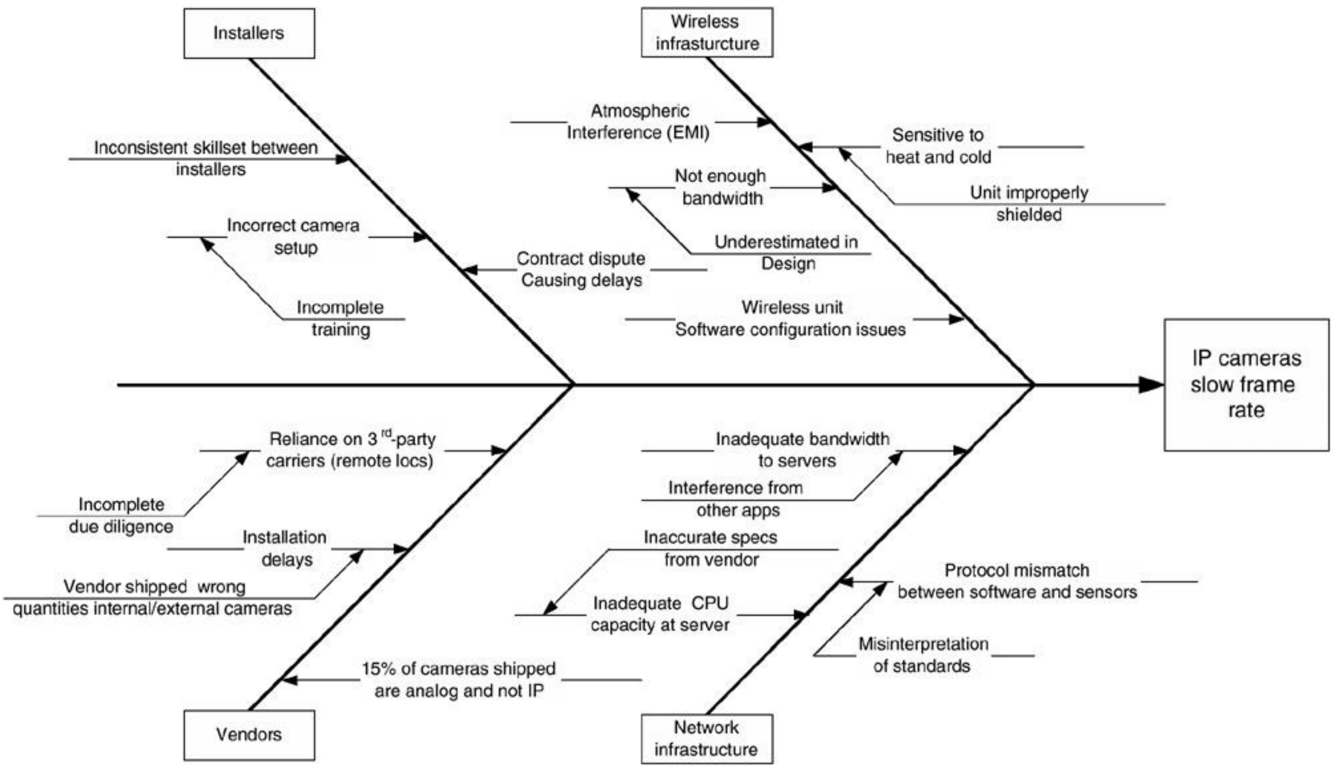
To visualize the root causes, which may be multiple, an Ishikawa diagram (also known as a fishbone diagram) can be used in order to create a clear picture of the current situation and to map out the possible root causes (see Figure 4). (Perrin, 2008)

2.5 PERFORMANCE MEASUREMENTS

Using performance measures is a procedure aimed at collecting and reporting information regarding the performance of an operation or individual parts thereof. This procedure can help the organisation to define and measure the goals it is aiming to achieve.

In the industry, performance measures are most often denoted as KPIs (Key Performance Indicators). Widely used KPI metrics are, for instance, cycle time, Mean Time Between Failure (MTBF) and utilisation. (Taylor Fitz-Gibbon, 1990)

Halachmi (2005) elaborates on the logic of reasons in support of introducing performance measurement as a promising way to improve performance. This strengthens the motives for measuring the performance of the operations.



Picture: Real World Project Management

Figure 4 - Ishikawa diagram

"*If you do not measure results, you cannot tell success from failure…*
If you cannot recognize failure, you will repeat old mistakes and keep wasting resources.
If you cannot relate results to consumed resources, you do not know what is the real cost..."

(Halachmi, 2005, p.504)

2.5.1 Mean Time Between Failures (MTBF)

Mean Time Between Failures (MTBF) is a measure of asset reliability. It is the average time between one failure and another failure for repairable assets (see Equation 10). An increasing MTBF indicates improved asset reliability. MTBF is best when used on asset or component level and should be performed on critical assets and trended over time. Low MTBF numbers should be approached with analysis (i.e., root-cause failure analysis (RCFA) or failure mode and effect analysis (FMEA)) in order to identify how the asset reliability can be improved. (Gulati, 2009)

2.5.2 Mean Time To Repair (MTTR)

Mean Time To Repair (MTTR) is a measure of the average time required to restore an asset's back to working condition (see Equation 11). In the context of maintenance, MTTR is comprised of two parts; the first is the identification of the problem and the required repairs; the second is the actual repair of the equipment.

One factor that will influence MTTR is the severity of the breakdown; another factor is the quality of the maintenance itself. A high MTTR should be approached with good troubleshooting methods, to quickly identify the root cause, and the maintenance actions should be reviewed regularly to identify improvement opportunities. (Mahadevan, 2009)

2.6 Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a lean manufacturing technique used to analyse the flow of materials and information in a system.

Value Stream Mapping involves all process steps, both value added and non-value added ones. In that way Value Stream Mapping can be used as a visual tool to help identify the hidden waste and sources of waste. Preferably, a current state map should be drawn to document how things actually proceed in the process. Thereafter, a future state map should be developed to shape a lean process which has eliminated root causes of waste.

Rich et al. (2006) defined the seven Value Stream Mapping tools as:

- Process Activity Mapping
- Supply Chain Responsiveness Matrix
- Product Variety Funnel
- Quality Filter Mapping
- Forrester Effect Mapping
- Decision Point Analysis
- Overall Structure Maps

$$MTBF = Uptime \;/\; Number\ of\ stops \qquad \text{Equation 10}$$

$$MTTR = \frac{Equipment\ Downtime\ Time}{Number\ of\ stops} \qquad \text{Equation 11}$$

2.7 RACI MATRIX

In a large organisation where responsibilities are divided between several parties and decisions impact many core functions, it is important that responsibilities are clear and involve different parties across the firm, especially in the decision-making process. The RACI Matrix is a method to manage decision allocation processes (see Table 1). RACI is an acronym for Responsibility, Accountability, Consulting and Information and stands for different roles in the decision process. (Dressler, 2004)

Dressler (2004) defines the building blocks of the RACI Matrix as follows:

- Responsibility (R) – The role responsible for decisions that fall under their area of responsibility within the organisation. This is an active and important role in the decision making process.

- Accountability (A) – This role is the person in charge of the individual taking on the “Responsibility” role and carries the accountability for the decision made.

- Consulting (C) – This role is not accountable or responsible for the consequences of the decision made but shall be consulted in the decision making process.

- Information (I) – This group includes other persons in the organisations that will be impacted by the decision and its outcome shall be kept in the information loop.

According to Dressler (2004), the RACI Matrix is used by many effective organisations to clarify ambiguous decision areas and solve decision conflicts upfront. This to give people a clear understanding about their roles in regards to contributing to an efficient decision making process.

Table 1 – An example of how a RACI Matrix can be created. R=Responsible, A=Accountable, C=Consulted, I=Informed.

	Person A	**Person B**	**Person C**	**Person D**	**Person E**
Decision A	A	C		I	R
Decision B	R	A	I		C
Decision C		C	R	A	I

2.8 PLATINUM

Platinum was discovered in 1735 in South America by Ulloa and can be found occurring naturally, accompanied by small quantities of iridium, osmium, palladium, ruthenium and rhodium, all of which belong to the same group of metals, the Platinum Group Metals (PGM) (The PGM Database, 2012). Platinum is one of the rarest elements in the Earth's crust and has an average abundance of approximately 5µg/kg. Other precious metals like gold, copper and nickel denote concentration in ores in percentages, but platinum denotes this in parts per million. Based on a typical conversion rate of 25%, 14 tons of ore are required to produce 10 grams of platinum. (Probert, 2012)

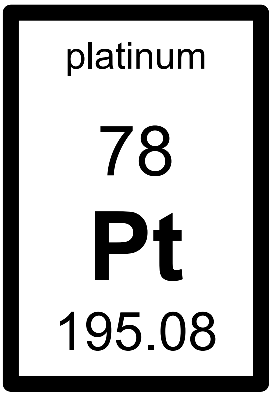


Figure 5 – Platinum in the periodic system

Platinum, iridium and osmium are the densest known metals. Platinum is 11% denser than gold and about twice the weight of the same volume of silver or lead. Platinum is soft, ductile and resistant to oxidation and high temperature corrosion. It has widespread catalytic uses. (Platinum Today, 2012)

In 2009, approximately 45% of the world's platinum was used in automotive catalytic converters, which reduce noxious emissions from vehicles. Jewellery accounted for 39% of demand and industrial uses accounted for the rest. (Anglo Platinum, 2011) Examples of its industrial uses are high-temperature electric furnaces, coating missile nose cones, jet engine fuel nozzles and gas-turbine blades. These components must perform reliably for long periods of time at high temperatures under oxidising conditions. Platinum is also used as a catalyst in cracking petroleum products. Currently there is a high interest in the use of platinum as a catalyst in fuel cells and in antipollution devices for automobiles. (The PGM Database, 2012)

The price of platinum has varied widely; in the 1890's it was cheap enough to be used to adulterate gold. But in 1920, platinum was nearly eight times as valuable as gold. The spot price on 2012-08-15 was approximately 1395 USD/oz t (1 oz t = 31.103 g), which can be compared to the gold price for the same day; 1594 USD/oz t (Kitco, 2012).

A comparison between platinum and its more well-known periodic table neighbour – gold can be viewed in Table 2.

Table 2 - A comparison between platinum and gold.

Freely from The PGM Database (2012)

	Platinum	Gold
Chemical Symbol	Pt	Au
Atomic number	78	79
Atomic weight	195.084	196.967
Density (g/cm^3)	21.45	19.30
Melting point (°C)	1769	1064
Vickers hardness (MPa)	549	216
Electrical resistivity (nohm-cm at 20°C)	105	22.14
Tensile strength (MPa)	125-240	120

2.9 EXTRACTION OF PLATINUM-GROUP METALS (PGM'S)

To get pure platinum a long process has to be followed. The extraction of platinum-group metals is described by Crundwell, et al. (2011) in the following five steps:

- Step one is to mine ore with a high concentrate of platinum-group metals while leaving rock lean in platinum-group metals behind.
- Step two is to comminute the mined ore into powder and isolate the platinum-group elements in the ore by creating a flotation concentrate consisting of nickel-copper-iron sulfides that has a high content of platinum-group elements.
- Step three is to smelt and convert this concentrate to a nickel-copper sulphide matte that is richer than the concentrate in platinum-group metals.
- Step four is to produce a, either through magnetic concentration or by leaching separate platinum-group elements in the converter matte, very rich platinum-group metal concentrate containing about 60% platinum-group elements.
- The last step is to refine this concentrate to individual platinum-group metals with purities in excess of 99.9%.

In general the concentrating and smelting/converting are done in or near the mining region while the refining is done in the region or in distant refineries. (Crundwell et al., 2011)

CHAPTER THREE
METHODOLOGY

In this chapter the methodology of the thesis will be presented and analysed in order for the reader to better understand the approach leading up to answering the research questions and fulfil the project scope. First, the research strategy and approach are presented. Next, details are given regarding the data collection methods used in the thesis project. Finally, reliability, validity and ethical aspects of the study are discussed.

3.1 Research Strategy

The research has been conducted in collaboration with the stakeholders at Mogalakwena North Concentrator (MNC), in order to jointly solve the problem. This is, according to Bryman and Bell (2011), a typical case where action research should be chosen as a research strategy, since answering the research questions demands an iterative process. Action research also allows the researchers to keep an open mind toward the problem at hand and to go back and forth between theory and practice in order to compare the results from data collection with theory, and to generate a thorough analysis which can be revised.

The assumption in action research is that the natural surroundings, in which the problem occurs, is the best place to study the problem. The data collection associated with action research includes both qualitative and quantitative methods. Qualitative research is a research in which words are more emphasised than quantities during data collection, whereas quantitative research puts more emphasis on quantified data.

Grounded Theory

A proper methodology when conducting action research is to use Grounded theory, which is defined as theory that is "*derived from data, systematically gathered and analysed through the research process*." (Strauss & Corbin, 1998, pp.12). This implies that data collection, analysis and eventual theory are closely related in an iterative process. Strauss and Corbin (1998) claim that grounded theories, since they are drawn from data, are likely to offer insight, enhance understanding and act as a meaningful guide.

Long-term success

Action research is also an appropriate strategy when looking at the long term success of the project, long after the completion of the thesis. In order for the new activities to be deeply rooted within the organisation it is very beneficial that key power groups within the organisation have been a part of the improvement process from the beginning (Nadler & Tushman, 1997). This strategy also makes it easier for the researchers to truly understand the system since it demands a lot of interaction between the different stakeholders (Bryman & Bell, 2011).

3.2 Research Approach

The chosen approach for this thesis is an abductive one. When using an abductive approach theory, empirical data and analysis are developed simultaneously in an iterative process (Bryman & Bell, 2011). This research approach is suitable when using action research since it involves the mind-set of involving theory and empirical information at the same time in order to develop an analysis that will answer the research questions. As the understanding of the situation increases, the need for new theory will most likely occur and this suits the description of an abductive approach very well.

3.3 Theory

Before travelling down to South Africa the pre-study was initiated in order for the researchers to gain the basic knowledge needed to understand the problem, become familiar with the available process data and the available theories in the area. Since Anglo American Platinum already used

OEE as a measure, the study of OEE and therefore also TPM became a natural part of the studies. TPM also led the path to studies of other maintenance fields, such as Lean maintenance, which is closely linked to improving productivity. The studies of OEE were broadened by studying the economic factors associated with improving OEE numbers, which also provided arguments for working with OEE improvements.

After core studies regarding the process in general and TPM methodologies, methods for identifying bottlenecks such as Value stream mapping, were studied more closely since they offered a very clear path to evaluate the production chain and direct the improvements to the right sections.

The remaining part of the literature study was conducted during the empirical study on site in cases where the empirical findings resulted in new theoretical aspects to study. This is also in line with the chosen abductive approach (Bryman & Bell, 2011).

3.3.1 DATA COLLECTION METHODS

The data needed for this thesis has mainly been collected through interviews, observations and by using secondary data. Most of the quantitative data was collected through gathering data from the PI database whereas the qualitative data was collected through semi-structured interviews, which is also the usual first step of engagement in the action research approach (Scheinberg, 2009).

OBSERVATIONS

In order for the researchers to acquire their own understanding of the situation, observations were conducted on site. This helped with the understanding of the specific steps in the production process as well as the daily work and methods used. The observations also acted as indications of what theoretical fields were interesting for further study and in that way led to a more focused literature study.

INTERVIEWS

A major part of the qualitative data was collected through numerous interviews with persons involved in the production process as well as management. The character of the interview was dependent on the position of the interviewee and the type of information sought (qualitative or quantitative). The basic approach was an unstructured interview in order for the interviewee to further elaborate on the questions asked. In an unstructured interview, the interviewers do not follow a strict structure of questions, but instead might have only one or a few questions to answer. The interview therefore resembles a conversation. (Bryman & Bell, 2011)

SECONDARY DATA

The major part of the data is secondary in the sense that it stems from information from metallurgists and specialists, and that no long-term observations beside the machines have been conducted. Still, the data is in most cases measured over a long period of time, which in a sense increases its accuracy. This gathering of data also limited the cost of the project, though the information might be difficult to understand and interpret and there is always a risk that some important information may be left out of the material handed to the researchers (Bryman and Bell, 2011). The process data used for calculation can also be seen as secondary data. The process data comes from the PI database were more than hundreds of thousands of different measurement points are logged.

3.4 RELIABILITY

The reliability concerns the results of the project and whether they are repeatable or not (Bryman & Bell, 2011). Achieving high reliability when using action research is a difficult task since the purpose is to change people's mind-set and the environment in which they act. By taking field notes throughout the entire project and also by keeping a diary, the researchers' intention has been to write down all important aspects of the thesis. The research is based on a combination of quantitative and qualitative data compared with existing methodologies within the area of increasing productivity. This approach ensures that the results are best practice from a theoretical point of view applied in the specific context.

3.5 VALIDITY

The validity of the project deals with the issue of whether the right aspects were studied in order to answer the research questions. Bryman and Bell (2011) propose to measure four different aspects in order to determine the validity of the thesis; construct validity, internal validity, external validity and ecological validity.

3.5.1 CONSTRUCT VALIDITY

The construct validity is regarded as high since data triangulation was used in cases where previous measurements were compared with data collection on site. Since the researchers have spent extensive time on site, the possibility of measuring critical aspects on several occasions was good.

3.5.2 INTERNAL VALIDITY

The internal validity deals with the issue of causality. The internal validity is highly relevant to this thesis since one research question aims to explore how certain changes affect the productivity of the process. The cause and effect relations are closely linked to the internal validity and these have been tested through triangulation and pattern matching. The validity has also been ensured by using well known methods and tools such as TPM, OEE and Lean.

3.5.3 EXTERNAL VALIDITY

At first, the external validity can be regarded as rather low since the study aims at improving the specific site in question. However, one of the research questions (number 1, see section 1.6) deals with how to develop a method, applicable at a general plant, to define and rank process units, which gives the thesis an increased external validity. To create an external valid thesis, proven methods have been used and general equations and definitions have been presented. This will help others to interpret the content of the thesis into other contexts and therefore increase the external validity. The aim for the researchers has been to develop an aggregated method which is generic and can be successfully implemented at similar plants.

3.5.4 ECOLOGICAL VALIDITY

The ecological validity concerns whether the findings are applicable to everyday life. In this case, the findings are highly applicable to day-to-day operations in the process. Since the data has been collected from the daily operations and improvements have been done in the actual production equipment, even though in a small scale at first, the ecological validity has to be considered as high. The pitfall might be that of the Hawthorne studies, which implies that people perform better just because they are being studied. Due to the long time period and the size of the production system this has to be considered as a low risk, but should still be kept in mind in projects of this kind.

3.6 ETHICAL ASPECTS

The researchers believe that a well-functioning mining industry in the region benefits all stakeholders and that this thesis should be a part of that development. The aim of this thesis is ultimately to increase the competitiveness of the company and the region, which has been a guideline throughout the project. Interviewees and other participants in this research have been informed about the purpose and have had the option to decline. This is to ensure that the participants do not feel harmed due to lack of informed consent, invasion of privacy or deception (Scheinberg, 2012).


VERLINDE

CHAPTER FOUR
DATA

This chapter will first present how the quantitative and qualitative data has been gathered. Next, the empirical data, including a process map, presentation of the units included in the project as well as some remarkable facts about the comminuting units, are presented. The quantitative and qualitative data has, together with the empirical data, served as input to the obtained results of this Master's thesis project.

4.1 Quantitative Data

Most of the quantitative data has been extracted from a highly technological process data system which collects and stores process data continuously in a database. This is known as the PI-system and PI-database. The PI-database consists of hundreds of thousands of measurement points, called tags, which can be manipulated and combined in almost limitless combinations.

To provide a picture of how the developed tool (called the Overall Productivity Tool (OPT)) uses tags from the PI-database to calculate the required metrics, see Table 3. The table displays the measures used for process area 406 to perform the required calculations.

Quantitative data has also been gathered through interviews and observations. When applicable, technical specifications have been gathered from original plant drawings.

Table 3 – The data extracted from the PI-database in order to calculate the OEE measures for area 406

UNIT	MEASURE	UNIT	MEASURE
HPGR Crusher 406-CR-001	Power [kW]	**Conveyor 406-CV-003**	Running [ON/OFF]
HPGR Screen 1 406-SC-001	Running [ON/OFF]	**Conveyor 406-CV-004**	Running [ON/OFF]
HPGR Screen 2 406-SC-002	Running [ON/OFF]	**Conveyor 406-CV-005**	Running [ON/OFF]
HPGR Silo Feeder 1 406-FE-001	Running time [min]	**Conveyor 406-CV-006**	Running [ON/OFF]
HPGR Silo Feeder 2 406-FE-002	Speed [%]	**Conveyor 406-CV-007**	Running [ON/OFF]
HPGR Feed Bin Feeder 1 406-FE-003	Speed [%]	**Belt scale 406-WT-010B**	Mass [t]
HPGR Feed Bin Feeder 2 406-FE-004	Speed [%]	**Belt scale 406-WT-402**	Mass [t]
HPGR Screen Feeder 1 406-FE-005	Speed [%]	**Belt scale 406-WT-416**	Mass [t]
HPGR Screen Feeder 2 406-FE-006	Speed [%]	**Belt scale 406-WT-433**	Mass [t]
Conveyor 406-CV-001	Running [ON/OFF]	**Lynxx camera (placed at 406-CV-007)**	Size [mm]
Conveyor 406-CV-002	Running [ON/OFF]		

4.2 Qualitative Data

The qualitative data has been gathered through unstructured interviews. In an unstructured interview, the interviewers do not follow a strict structure of questions, but instead might have only one or a few questions for the interviewee (Bryman & Bell, 2011). The interview therefore resembles a conversation. The unstructured personal interviews have been conducted both in Sweden and in South Africa.

During the pre-study in Sweden unstructured interviews were held with the following persons at Chalmers University of Technology from August 15th until September 10th:

- Prof. Magnus Evertsson, Chalmers Rock Processing Systems
- Dr. Erik Hulthén, Chalmers Rock Processing Systems
- Gauti Asbjörnsson, PhD student, Chalmers Rock Processing Systems
- Johannes Quist, PhD student, Chalmers Rock Processing Systems
- Torbjörn Ylipää, Senior Lecturer in Producton Systems
- Ludvig Lindlöf, PhD student at the Division of Operations Management

During the time spent at the University of Cape Town in South Africa, unstructured interviews were held with Dr. Aubrey Mainza, Department of Minerals Research, from September 12th until December 20th.

Unstructured interviews were held on site with persons with the following positions from September until mid-December 2012:

- Plant Manager
- Technical Manager
- Metallurgist for Dry Section, Milling & Classification and Flotation
- Metallurgist Graduates for Milling & Classification and Flotation
- Engineering Specialists
- Production Leaders
- Operators
- Planners

The following persons at Anglo American Platinum in Johannesburg have been consulted during the project (September - mid-December 2012):

- Head of R&D
- Head of Control and Instrumentation
- Head of Engineering
- Leader Process Control Engineer
- Control Engineer

Observations have been made on site from September to December 2012.

4.3 Empirical Data

The empirical study serves to give the reader an understanding of the current state in interesting areas of the operations, both in production technical and in organisational terms. Along with the theoretical framework it will serve as a basis for the analysis. The data presented has been captured during interviews and observations on site.

4.3.1 Organisational Chart

To understand the organisational structure at Mogalakwena North Concentrator, an organisational chart (Appendix I) over the divisions involved in areas critical for this project, has been developed. This chart formed the basis for an understanding of the divisional and inter-divisional processes.

4.3.2 Process Map

The comminution circuit is divided into seven sub-areas (102, 401, 405, 406, 407, 408 and 440, see Figure 6). These areas are mapped in more detail in Appendix I. Except for the information gathered from interviews and observations; this map contains information from the original plant drawings.

Comminution

Comminution is a part of the concentrator process and is defined as:

"*The action of reducing a material, especially a mineral ore, to minute particles or fragments.*"
(Oxford Dictionaries, 2012)

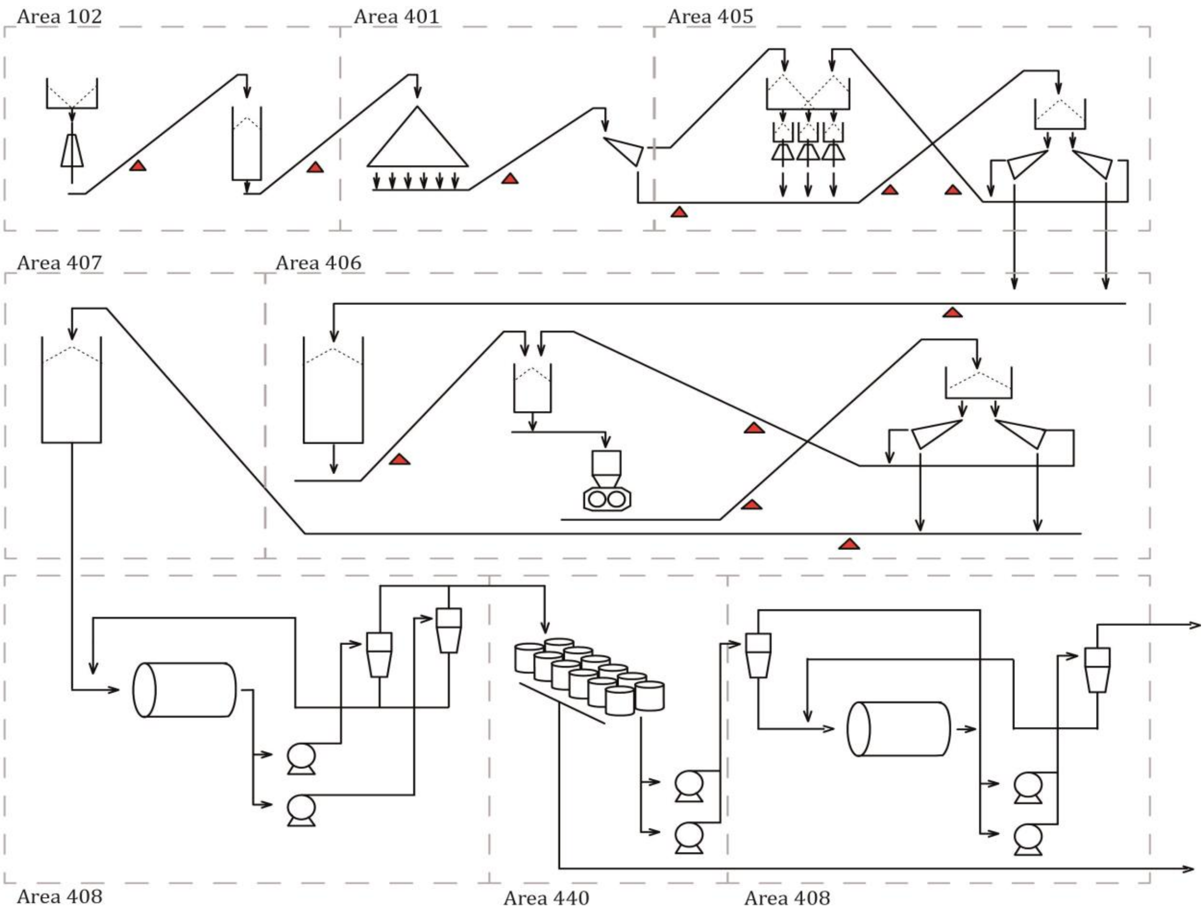


Figure 6 - Process map displaying area 102-408 at MNC (For more detailed maps, see Appendix I)

4.3.3 Units in a Concentrator Plant

In the following section, the different types of process units included in the project and their dedicated tasks in the plant will be described.

Units dedicated to comminution in a concentrator are, for instance, the primary crusher, secondary crusher, High Pressure Grinding Roll crusher (HPGR) and the ball mill.

Conveyor

A conveyor is a unit which has the purpose of moving or transporting bulk material or objects in a path predetermined by the design of the conveyor. The conveyor can be horizontal, inclined or vertical in its design. At MNC, all bulk transports are performed by conveyors and the total length of all conveyors is approximately 9000 metres.

Classifier

A classifier is a unit which classifies the material physically by separating it based on its particle size. At a concentrator this can be performed by, for instance, a grizzly, screen or cyclone, all which have the same purpose but perform the separation of material in different ways.

Feeder

A feeder is a unit that puts material in motion. Its purpose is to regulate the amount of material that, for example, is fed into a crusher or from a storage silo onto a conveyor.

4.3.4 Area Affiliations of Units

The following section will present the name and type of the units included in the project based on their area affiliation. The presentation order of the following tables is equal to the material flow order in the process.

Area 102

Table 4 – The name and number of units in process area 102

TYPE OF UNIT	NO. OF UNITS	NAME
Comminution unit	1	102-CR-001 Primary crusher
Feeder	2	102-FE-001 & 102-FE-002
Conveyor	2	102-CV-001 & 102-CV-002
Classifier	0	-

Area 401

Table 5 - The name and number of units in process area 401

TYPE OF UNIT	NO. OF UNITS	NAME
Comminution unit	0	-
Feeder	6	401-FE-001 - 401-FE-006
Conveyor	1	401-CV-001
Classifier	1	401-GY-001 Grizzly

Area 405

Table 6 - The name and number of units in process area 405

TYPE OF UNIT	NO. OF UNITS	NAME
Comminution unit	3	405-CR-001 – 405-CR-003 Secondary Crushers 1,2,3
Feeder	5	405-FE-001 – 405-FE-005
Conveyor	6	405-CV-001 – 405-CV-006
Classifier	2	405-SC-001 & 405-SC-002 Secondary Screen 1 & 2

AREA 406

Table 7 - The name and number of units in process area 406

TYPE OF UNIT	NO. OF UNITS	NAME
Comminution unit	1	406-CR-001 HPGR Crusher
Feeder	6	406-FE-001 – 406-FE-006
Conveyor	7	406-CV-001 – 406-CV-007
Classifier	2	406-SC-001 & 406-SC-002 HPGR Screen 1 & 2

AREA 407

Table 8 - The name and number of units in process area 407

TYPE OF UNIT	NO. OF UNITS	NAME
Comminution unit	0	-
Feeder	2	407-FE-001 & 407-FE-002
Conveyor	2	407-CV-001 & 407-CV-003
Classifier	0	-

IN TOTAL

Table 9 - The total number of units in process included in this project

TYPE OF UNIT	NO. OF UNITS
Comminution unit	5
Feeder	21
Conveyor	15
Classifier	5

4.3.4 Comminution Unit Facts

Since Mogalakwena North Concentrator is designed to be the world's largest single stream platinum concentrator (Mining Weekly, 2008), it has several remarkable units.

Crushers

The circuit includes in total three crushing systems – one primary crusher, three secondary crushers and one tertiary crusher (HPGR).

The primary crusher, which is the largest primary gyratory crusher in the world, weighs 480 tonnes, is 60-feet (18.3 m) in diameter and has a 1 MW motor. The crusher can handle ore pieces up to one square sectional metre and has a maximum capacity of 3000 tonnes per hour.

The secondary crusher system consists of three identical hydrocone crushers with different settings due to the different sized materials with which they are fed. This design makes the plant setting quite rare and requires customised equipment performance calculations.

The tertiary crusher is a HPGR (High Pressure Grinding Roll) crusher, which utilises two 100 tonne rolls, one fixed in position and the other moving horizontally to adjust the gap between them, to crush the ore. Mogalakwena North Concentrator is the first platinum plant in the world to utilise a HPGR crusher for this purpose.

Mills

The primary and secondary mills are the two first gearless mill drives (GMD) at Anglo Platinum. The drives are powered by a 17.5 MW motor, five times as big as a similarly-sized throughput mill. When the plant was commissioned in 2009 these GMDs, with a diameter of 26 feet (7,9 m), were the largest installed in the world.. (Probert, 2012)

Lynxx Cameras

The plant has five Lynxx cameras, which optically determine the particle size of the material which is being transported on a conveyor. The map displaying the installed positions can be viewed in Appendix III.

4.4 Value Stream Maps

The Value Stream Mapping process is based on the interview results and observations and consists of individual maps of the current state of processes and the operations found to be of interest for this project. The maps were developed to give an enhanced understanding of the current state of the processes and are presented here to give the reader an enhanced understanding of the state.

Crusher and Mill Stops Reporting Procedure Map

An analysis of the production process called Pain analysis has been developed by the Master's thesis writers. To be able to perform this analysis, data from crusher and mill stops is required. To understand the internal reporting process for these reports the entire process was mapped accordingly (Figure 4).

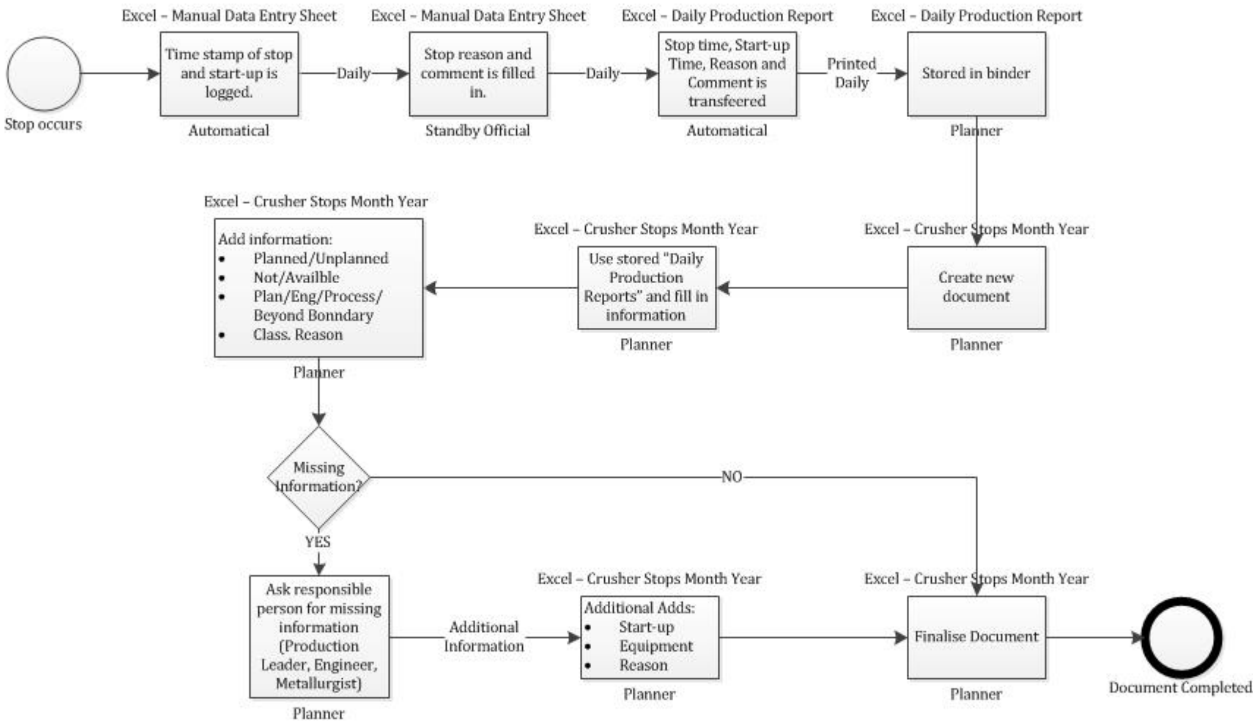


Figure 4 – Current Crusher and Mill Stops Reporting Procedure Map

The Crusher and Mill Stops Reporting Procedure Map displays the procedure for reporting the stops. It can be seen that the input to the report is a daily activity, whereas the submitting of the report is done on a monthly basis. This can be regarded as a poorly synchronised procedure and will eventually result in missing or delayed data regarding the stops. The analysis of crusher and mill stoppages will, due to this process, only be possible once a month, which is insufficient for the Pain analysis.

JOB CARD INSPECTIONS MAP

A plant's performance is highly affected by the quality of the performed maintenance work. Due to this, the current process for daily maintenance work at the plant was mapped to acquire an understanding of how it works. The map of the job card inspections can be viewed in Appendix IV.

CHAPTER FIVE

RESULTS

This chapter will present the results that have been obtained in the project. The results are presented in three distinct sections – Define, Develop and Design. The same sections are used in the discussion and conclusions in order for the reader to more easily follow the red thread.

CHAPTER 5 – INTRODUCTION TO RESULTS

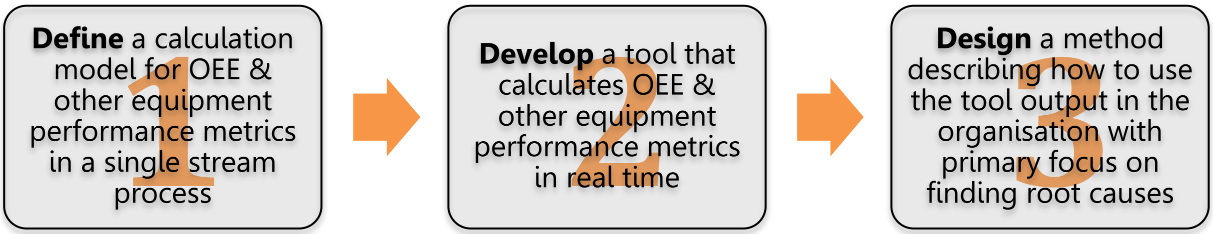


Figure 7 – Project phases

The results are presented according to the three distinct project phases (see Figure 7). The first phase was to define a calculation model for OEE and other equipment performance metrics. The second phase was to develop a tool (OPT) which uses the calculation model to perform real time calculations of OEE and other equipment performance metrics. The third phase was to design a methodology to use in the organisation to find root causes to productivity limiting issues. Moreover, this chapter includes a presentation of how to calculate OEE in a General Single Stream Process and results from the new procedure for Crusher and Mill Stops Reporting that was introduced at MNC by the two Master's thesis writers.

5.1 CALCULATION MODEL

In the following section, the results of the first phase (see Figure 8) of this project will be presented. This part contains the calculation model for OEE and other equipment performance metrics in a 24/7 single stream comminution process.

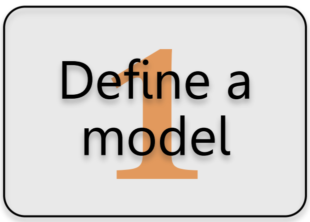


Figure 8 – Project phase 1 - Define

The calculation model covers the five metrics; OEE, Availability, Utilised Uptime, Mean Time Between Failure (MTBF) & Mean Time To Repair (MTTR) and Pain (see Figure 9). The final calculation for these metrics will be presented in the following sections. The calculations are based on the Anglo American Equipment Performance Metrics definitions and have taken inspiration from a customised calculation model developed by the Master's thesis writers (see section 5.4) to suit the process of MNC, since the Anglo American definition is not comprehensive enough to be used in this process. However, since it is a company standard, the aim has been to use it as extensively as possible and it has been a wish from the company not to deviate from the standard whenever possible.

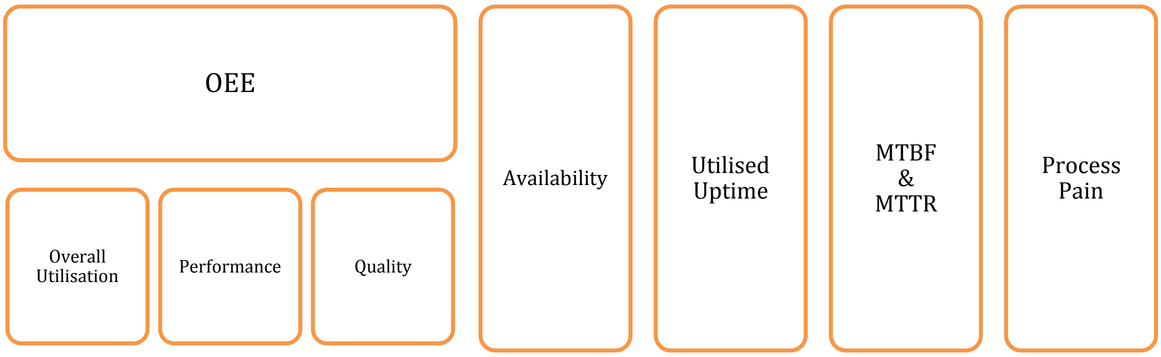


Figure 9 - Equipment metrics included in the calculation model

5.1.1 Final OEE Calculation

The final OEE equations used in all calculations will be presented in this section. The metrics consist of three parts - Overall Utilisation, Performance and Quality (see Equation 12). The three components of OEE can also be used as individual metrics. The components of the OEE equation are presented in the following sections.

Overall Utilisation

To determine the utilised time of a unit, the ratio between Primary production time and Total time is used. Primary production time is defined as "Time equipment is utilised for production" and Total time is defined as "The total possible hours available". These definitions are taken from the Anglo American Equipment Performance Metrics. For explanations of the equation components, see Figure 10.

To clarify, Overall Utilisation is the metric corresponding to the general OEE calculation's measure known as Availability, displaying the equipment usage, however *not* calculated in the same way or with the same result.

Performance

Equipment Performance is calculated according to the Anglo American Equipment Performance Metrics as the ratio between Actual Production Rate and Target Production Rate. The Performance essentially indicates how efficiently the unit has been working, i.e. to what degree the unit has been doing things in the correct way.

$$OEE = Overall\ Utilisation\ x\ Performance\ x\ Quality \qquad \text{Equation 12}$$

$$Overall\ Utilisation = \frac{Primary\ Production}{Total\ time} \qquad \text{Equation 13}$$

$$Performance = \frac{Actual\ Production\ Rate}{Target\ Production\ Rate} = \frac{Actual\ Production\ Achieved\ /\ Primary\ Production}{Target\ Production\ Rate} \qquad \text{Equation 14}$$

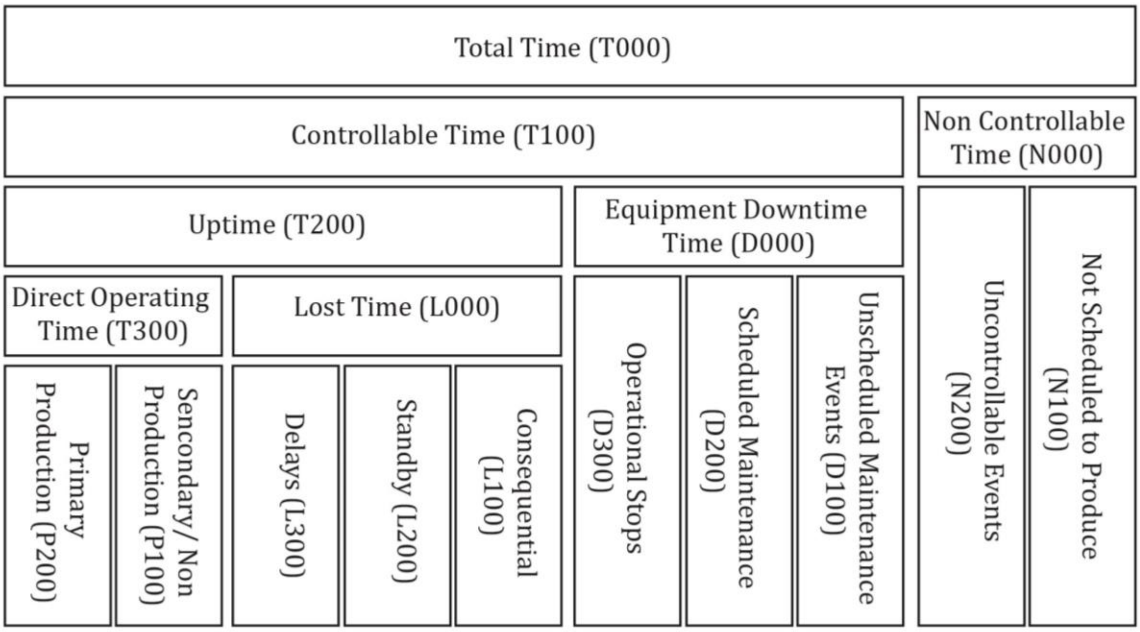


Figure: Freely after Anglo American Equipment Performance Metrics Time Model

Figure 10 - Time definitions by Anglo American Equipment Performance Metrics

The Actual Production Rate is the ratio between Actual Production Achieved and Primary Production, which both can be calculated with data drawn from the PI-database. The Target Production Rate, however, is an input measure which has to be defined for every single unit.

QUALITY

The method to calculate the product Quality was developed by the Master's thesis writers. The Quality looks at the particle size and shows to what extent the particle size is below the targeted size. The target and actual particle size concerns the P80 value, which is a commonly used value in the comminution industry. P80 is defined as the size where 80 percent of the material passes a certain upper size limit. The equation compares the Actual Particle Size at a certain point in the process to the Target Particle Size for that point (see Equation 15).

The Quality is defined as the mean deviation above Target Size as a percentage of the Target Size (see Figure 11). This implies that all particles below target size result in zero deviation, hence a 100% Quality. To achieve the metric Quality suitable for the OEE calculation and not the deviation, the ratio is subtracted from 1. For instance, if all particles are below Target Size, the Quality will be 100%. If some particles are above Target Size, the equation will compute their individual deviation from the Target Size. Together with the particle sizes below the Target Size, which all are regarded as having no

$$Quality = 1 - \frac{Mean\ deviation\ from\ Target\ Size}{Target\ Size} = 1 - \frac{\frac{\sum_{i=1}^{n} \left(Deviation\ from\ target\ size\right)_i}{n}}{Target\ Size} \qquad \text{Equation 15}$$

deviation, an average deviation is computed. This average deviation is then divided by the Target Size and subtracted from 1 to get a percentage between 0 and 100.

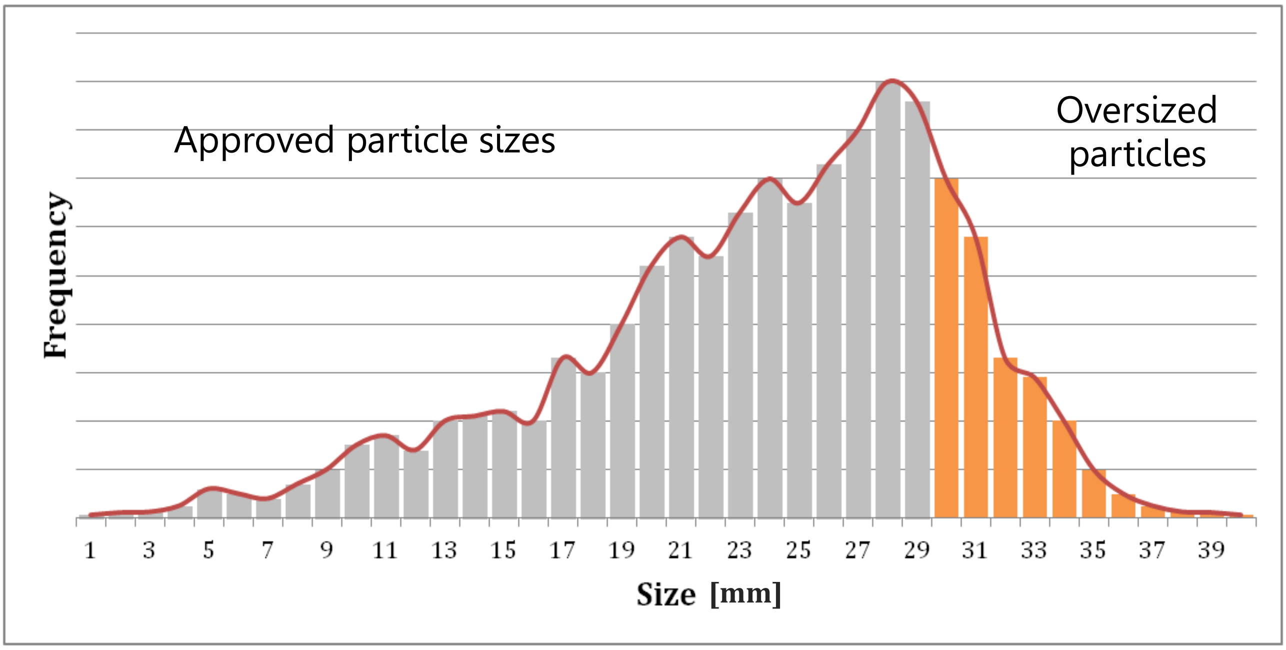


Figure 11 - Example size distribution of P80 with target size marked

5.1.2 Availability

OEE and its components is the first metric in the calculation model. The second metric is Availability.

In some cases, the Overall Utilisation equation is not sufficient and/or applicable, for instance when there is a lack of data. In that case, Availability (see Equation 16) is used. The Availability shows the percentage uptime of the unit and is defined as the ratio between Uptime and Total Time.

$$Availability = \frac{Uptime}{Total\ Time}$$ Equation 16

$$Utilised\ Uptime = \frac{Overall\ Utilisation}{Availability}$$ Equation 17

$$MTBF = \frac{Uptime}{Number\ of\ stops}$$ Equation 18

$$MTTR = \frac{Equipment\ Downtime\ Time}{Number\ of\ stops}$$ Equation 19

5.1.3 Utilised Uptime

The Master's thesis writers have developed a new metric to display the ratio between Overall Utilisation and Availability, called Utilised Uptime (see Equation 17). This is the third metric in the calculation model. The Utilised Uptime shows the percentage of the available time that is used for Primary Production. This metric is possible to compute for the units where Overall Utilisation can be calculated.

5.1.4 MTBF & MTTR

The fourth metric in the calculation model is the combination of Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR). These two metrics are calculated to give an indication of asset reliability and the quality of maintenance work. For explanations of the equation components, see Figure 10.

5.1.5 Pain Analysis

The fifth metric in the calculation model is Pain. In order to help focus the efforts in the daily work at the plant, this analysis tool, which includes a new way of displaying failures, has been developed by the Master's thesis writers. The analysis provides a metric called Pain and looks at how much pain a certain stop has caused a unit. Instead of the user being forced to look at and compare both the frequency of a stop and its downtime in order to find the most painful problem, Pain can be used to give an aggregated view.

The Pain is calculated as the product of frequency of the stop and total downtime caused by the stop (see Equation 20). This gives a total view of the pain the problem has caused. The unit of Pain is time (minutes) but can be regarded with minor importance since it does not display an actual downtime but the sum of all downtimes multiplied by the number of stoppages. Therefore, the Pain is used as a unit-less metric and displayed unit-less in the tool.

$$\begin{aligned}Pain_{failure,\ type\_x} &= Frequency\ of\ error \times Total\ downtime\ caused\ by\ error = \\ &= n_{failure,\ type\_x} \times \sum_{i=1}^{n} n_{failure,\ type\_x,n} \\ &= n_{failure,\ type\_x} \times \left(t_{failure,\ type\_x,\ 1} + t_{failure,\ type\_x,\ 2} + \ldots + t_{failure,\ type\_x,\ n}\right)\end{aligned}$$ Equation 20

Along with the Pain equation, the Master's thesis writers have developed the Pain diagram which displays the errors with the top 6 highest Pains, sorted in ascending order (see Figure 12). This diagram gives a clear view of the currently most alarming errors in the process.

To facilitate the drilling down in stop reasons, the frequency and downtime can be displayed and analysed in a pyramid diagram (see Figure 13).

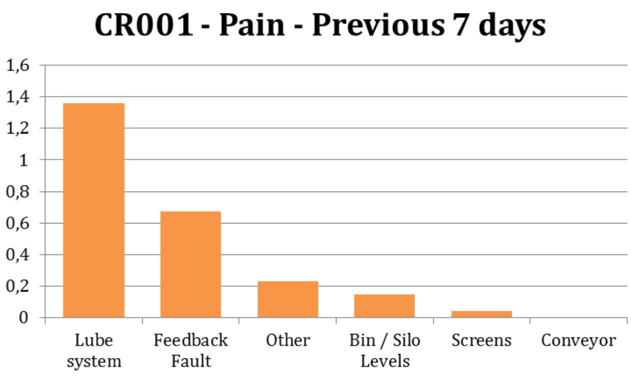


Figure 12 – The Pain chart as it is displayed in OPT

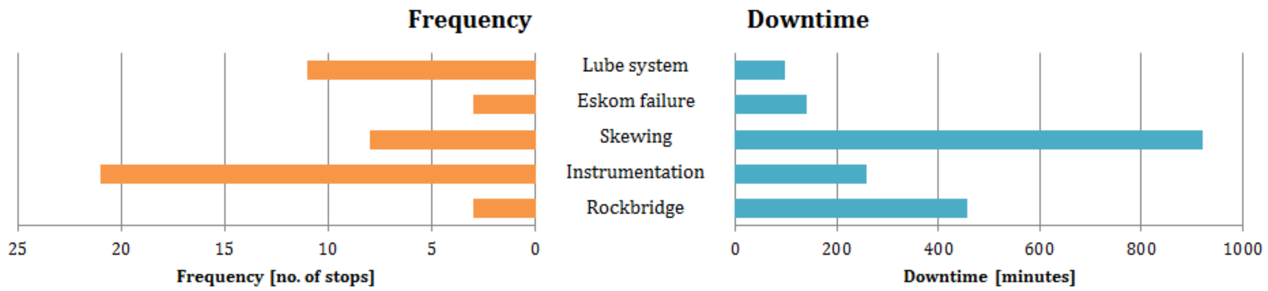


Figure 13 – Pyramid diagram of Pain components

5.1.6 Setting Filters & Target Values

In the calculation of Overall Utilisation, Availability, Performance and Quality target values are used. These target values are critical components of the calculations since they each have a large impact on the results. This section will present the methods used when determining the individual target values.

Overall Utilisation & Availability

The Overall Utilisation and Availability calculations use filters to determine in what type of activity the unit is engaging. For instance, when a comminuting unit is running above a certain power level, it is assumed to be performing primary production activities. In this project these levels have been determined based on a large amount of data analysis. These determined levels shall be reviewed periodically due to possible process changes.

PERFORMANCE

When calculating Performance, a Target Production Rate is used for comparison with the Actual Production Rate. The Anglo American Equipment Performance Metrics describes three ways of setting the Target Production Rate, these ways are as follows:

1. Best demonstrated production rate, which is defined as the best demonstrated performance determined by calculating the average of the five best monthly production rates.

2. Equipment nameplate/design capacity rate.

3. Budgeted production rate.

The Master's thesis writers propose a fourth way of setting target production rate. The fourth way should be based on the design capacity of the unit and take changes on parts and settings that have affected installed capacity into consideration. For a crusher, critical changes could, for instance, be changing chamber or closed side setting (CSS). Such changes will result in a capacity change and should therefore be taken into account when setting target production rates.

QUALITY

When calculating Quality, a Target Particle Size is used for comparison with the Actual Particle Size. The Target Particle Size at different points in the process has been set with advice from production experts at MNC. The target is based on the particle size demands of the downstream comminuting unit.

5.1.7 CLASSIFICATION

The equipment has been divided into four different classification groups; A, B, C and D. These have been made in order to divide equipment based on their complexity and need of monitoring. The available measuring points have also affected what group in which the units were placed. Table 10 presents the measurements for the different classification groups.

Table 10 – Classification of units

Classification	**A**	**B**	**C**	**D**
Equipment	Circuits	Comminution units	Supporting equipment (with available measures)	Supporting equipment (without available measures)
Details	OEE Overall Utilisation Performance Quality Availability Utilised Uptime	OEE Overall Utilisation Performance Availability Utilised Uptime MTBF MTTR Pain	Overall Utilisation Availability Utilised Uptime	Availability

5.2 THE OVERALL PRODUCTIVITY TOOL (OPT)

In the following section, the results of the second phase of this project will be presented.

Figure 14 – Project phase 2 - Develop

The result of the second phase of this Master's thesis project is a management tool which combines the parameters identified during the first phase and calculates them in real time. The tool displays charts and tables of equipment metrics and the metric Pain. The developed tool is called the Overall Productivity Tool (OPT). The abbreviation suits the purpose of the tool well since the word *opt* is defined as (Merriam-Webster, 2012):

> "*To make a choice; especially: to decide in favour of something*"

5.2.1 OPT STRUCTURE

The metrics in the tool are organised in a manner that provides a dynamic overview of the equipment in the process. OPT is built up of four modules in an excel document – OEE, OEE Table, Pain analysis and Stop Table. The modules will be presented in the following four sections. OPT includes the five metrics OEE, Availability, Utilised Uptime, Mean Time Between Failure (MTBF) & Mean Time To Repair (MTTR) and Pain Analysis. OPT is covering the process areas 102, 401, 405, 406 and 407 at MNC. Figure 15 displays the structure of OPT.

OPT is developed and programmed in Excel and Visual Basic Editor and has direct communication with the PI-database. The program extracts real time data from the PI-database and computes the defined metrics from the calculation model defined in the first phase of the project.

For detailed screen shots of the OPT software, see Appendix V.

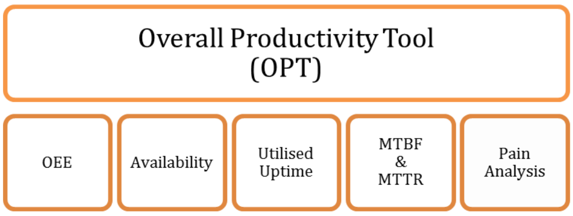


Figure 15 - Structure of OPT and its included metrics

5.2.2 OEE MODULE

The OEE module displays charts with the OEE for the circuit and the crushing unit in the monitored area. It also displays charts with the Overall Utilisation, Performance, Quality, Availability, and Utilised Uptime for the units included in the monitored area. The charts display data for the period of the previous 7 days as well as for the previous 30 days, which gives the user a presentation of the metrics in both short and medium term.

The charts displaying Overall Utilisation, Availability and Utilised Uptime are sorted in ascending order to visualise the units with lowest current values.

The charts displaying Quality and Performance show those values for the crushing unit in the monitored circuit as well as for the entire circuit (see Figure 21 & 17). In the OEE module, explanations of the charts and their metrics are provided to give a clear view of what is being presented. At the top of the sheet, the monitored time intervals are displayed.

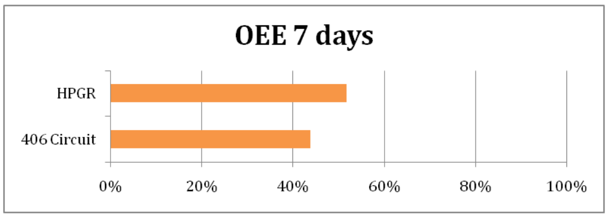


Figure 16 – OEE graph from OPT

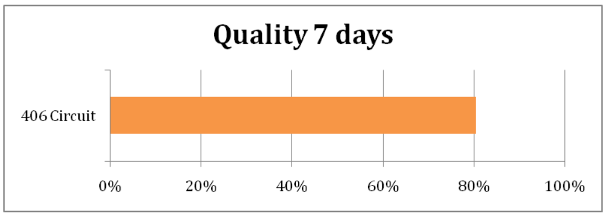


Figure 17 – Quality graph from OPT

Figure 18 – Availability graph from OPT

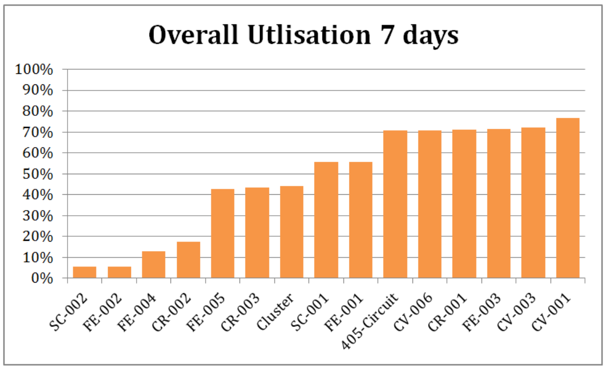


Figure 19 – Overall Utilisation graph from OPT

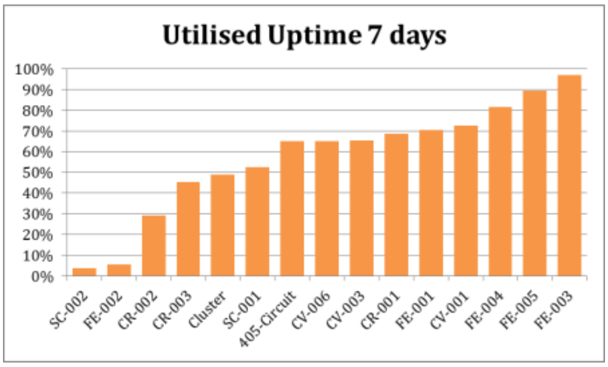


Figure 21 – Utilised Uptime graph from OPT

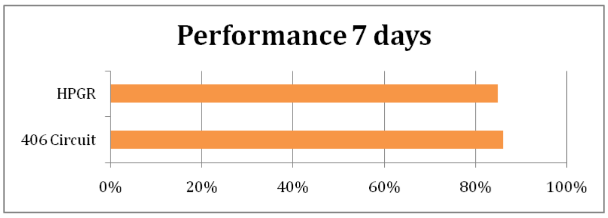


Figure 20 – Performance graph from OPT

5.2.3 OEE Table Module

The OEE Table module displays the components of the OEE calculations categorised by unit type (crusher, classifiers, feeders and conveyors). The OEE Table module provides the calculations with a transparency and can be used to acquire a more thorough understanding of the charts displayed in the OEE module. At the top of the module, the monitored time intervals are displayed. Additional metrics displayed in the module are Average Size and Average Deviation.

The definition of any displayed component can be viewed by hovering over the component name (see Figure 22, where the pointer is hovered over "Availability").

The displayed rates included in OEE have a colour code which visualises the current status. Green is for Satisfactory, yellow for Poor and red for Alarming.

The colour limits for the different units can be seen at the bottom of the sheet. The limits shall be set based on the business targets and can only be changed by the administrator of OPT.

5.2.4 Pain Module

Pain is a way of visualising the combination of stop frequency and downtime for a unit in the monitored area. The Pain Module in OPT displays charts with the top 6 Pains in the monitored process area sorted in descending order (see Figure 23).

At the top of the sheet, the monitored time intervals are displayed.

The charts are sorted in descending order to visualise which stop reasons currently are causing the greatest damage to the process. The stop reasons are labelled below each bar in the chart. The unit for the y-axis is thousand minutes, however, Pain is displayed as a unit-less metric.

Area 406 - OEE Table	Start Time: / End Time:	7 days	2012-11-18 14:31 / 2012-11-25 14:30	PM	2012-10-01 00:00 / 2012-10-31 23:59

	406 Circuit		HPGR	
	7 days	PM	7 days	PM
Total Time (T000):	10079,00	44639,00	10079,00	44639,00
Uptime (T200)	7775	36707	7995	33905
Direct Operating Time (T300):	[illegible]	23023	5923	22407
Availability:	[illegible]	[illegible]2,23%	79,32%	75,95%
Overall Utilisation:	[illegible]	[illegible]1,58%	58,77%	50,20%
Utilised Uptime:	[illegible]	[illegible]2,72%	74,08%	66,09%
Target Production Rate:	1450,00	1450,00	2600,00	2600,00
Actual Production Achieved:	130907,50	519143,61	212447,24	781755,08
Actual Production Rate:	1298,69	1352,93	2152,09	2093,33
Rate Achived:	89,56%	93,31%	82,77%	80,51%
Quality (P80):	91,84%	93,38%		
Average Size:	7,63	7,68		
Average Deviation:	-0,37	-0,32		
Overall Equipment Effectivenes	49,36%	44,94%	48,64%	40,41%

Availability = Uptime / Total Time

	406-SC001		406-SC002	
Classifiers	7 days	PM	7 days	PM
Uptime (T200)	7536	35650	7362	34801
Direct Operating Time (T300):	6422	21318	1866	7342
Availability:	74,77%	79,86%	73,04%	77,96%
Overall Utilisation:	63,72%	47,76%	18,51%	16,45%
Utilised Uptime:	85,22%	59,80%	25,35%	21,10%

	406-FE001		406-FE002		406-FE003		406-FE004		406-FE005		406-FE006	
Feeders	7 days	PM	7 days	PM	7 days	PM	7 days	PM	7 days	PM	7 days	PM
Uptime (T200)	6536	24054	6613	24480	7426	29131	5904	22488	7046	25850	6992	29068

Figure 22 - Information appearing when hovering over Availability

At the top of the sheet, above the charts, Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) are displayed for the crushing unit in the area.

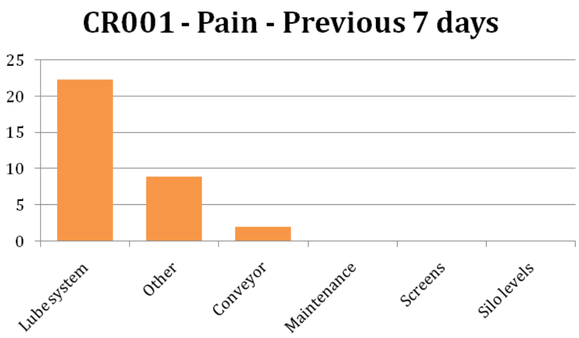


Figure 23 – Pain chart as it is presented in OPT

5.2.5 Stop Table Module

The Stop Table module presents the information upon which the Pain Analysis is based in a more detailed way (see Figure 24). The stop information is drawn from stop reporting through the PI-database. The following information is presented to the user:

- Stop time: The time the unit stopped
- Start-up time: The time the unit started up after the stop
- Duration: The duration of the stop
- Stop reason: The reason for the stop
- Manually entered comment: Possible manually entered comment by stand-by official
- Downtime categories
  - Downtime sub-category code
  - Downtime sub-category name
  - Downtime category code
  - Downtime category name
- Scheduled/Unscheduled: Indicates if the stop was scheduled or not

The downtime categories are used to facilitate the allocation of stops in alignment with the Anglo American Equipment Performance Metrics Time Model.

At the top of the sheet the total number of stops and the total downtime in the chosen time interval are displayed. At the extreme top of the sheet, the monitored time intervals are displayed.

Area 405 - Stop Table CR001 — **Start time:** 2012-11-24 16:08 — **Stop time:** 2012-12-01 16:07

Total no. of stops: 9
Total duration of stops (minutes): 1441
Total duration of stops (days): 1,00

DATE		DURATION	STOP REASON	COMMENTS	DOWNTIME SUB-CATEGORY		DOWNTIME CATEGORY		SCHEDULING
STOP TIME	START-UP TIME	Duration (HH:MM:SS)	Stop reason	Manually entered comment	Downtime sub-category code	Downtime sub-category	Downtime category code	Downtime category	Scheduled/ Unscheduled
2012-11-25 08:34	2012-11-25 12:34	04:00:29	Maintenance	Hydraulic pipe on CR3	D100	Unscheduled Maintenance Event	D000	Equipment Downtime	Unscheduled
2012-11-25 16:58	2012-11-25 17:12	00:14:24	Bin / Silo Levels	High screen bin level	D300	Operational Stop	D000	Equipment Downtime	Unscheduled
2012-11-26 10:09	2012-11-26 10:20	00:11:31	Other	Belt tear detector	D000	Other Downtime	D000	Equipment Downtime	Unscheduled
2012-11-27 11:45	2012-11-27 15:37	03:51:50	Maintenance	#N/A	D100	Unscheduled Maintenance Event	D000	Equipment Downtime	Unscheduled
2012-11-29 10:42	2012-11-29 11:03	00:21:36	Other	changing idlers	D000	Other Downtime	D000	Equipment Downtime	Unscheduled
2012-11-29 16:50	2012-11-30 02:58	10:07:41	Bin / Silo Levels	HPGR silo full	D300	Operational Stop	D000	Equipment Downtime	Unscheduled
2012-11-30 10:40	2012-11-30 13:20	02:39:50	Maintenance	measuring liners	D100	Unscheduled Maintenance Event	D000	Equipment Downtime	Unscheduled
2012-11-30 18:02	2012-11-30 20:31	02:28:19	Lube system	low pinion shaft pressure	D100	Unscheduled Maintenance Event	D000	Equipment Downtime	Unscheduled
2012-11-30 22:14	2012-11-30 22:20	00:05:46	Bin / Silo Levels	high screen bin level	D300	Operational Stop	D000	Equipment Downtime	Unscheduled

Figure 24 – The stop table as it is presented in OPT

5.3 OPT METHOD

In the following section, the results of the third phase of this project will be presented.

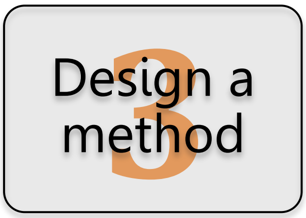


Figure 25 – Project phase three - Design

The result of the third phase of this Master's thesis project is a methodology describing how to use the output of OPT in a productive way with primary focus on finding root causes to productivity limiting issues and follow up on action taken. The three supportive areas

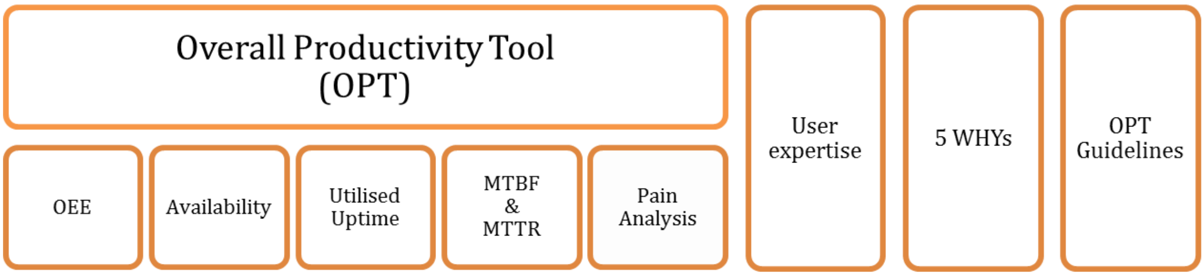


Figure 26 – A model describing the intended usage of OPT

to the right of OPT (in Figure 26) are User expertise, the 5 WHYs and OPT Guidelines. These areas will be presented in more detail here.

5.3.1 USER EXPERTISE

In order to achieve a valid result when analysing the OPT output, a certain user expertise is required. The user shall possess good knowledge of the process and have previous experience from working with the process. It is also important that the user possesses a systematic problem solving technique.

The success of the OPT method is also determined by its users and their expertise. It has been seen that a cross functional user group, i.e. a group consisting of personnel from different functional groups of the organisation, including for instance both technical and engineering staff, is the most successful combination. The group members' different backgrounds help to create a broader view of the OPT output. If a cross functional group is used, it also helps to increase the collaboration between departments and limits dual work. The OPT Method's incorporated action list facilitates tracking of issued actions, which has been seen necessary in large organisations. Another positive effect is that cross-functionality unites the users among a common systematic problem solving technique.

5.3.2 FIVE WHYS

The root cause finding technique, the 5 WHYs, is proposed as a suitable method to use to find root causes to issues encountered when analysing the OPT outcome. For more information on the 5 WHYs, see section 2.2.1 Five Whys.

5.3.3 OPT GUIDELINES

The Master's thesis writers have developed user guidelines for how to use OPT to facilitate usage of the tool. The guidelines will be presented here and consist of the following documents:

- OPT Manual
- OPT Meeting Procedure
- OPT Action List

OPT MANUAL

The OPT Manual is a complete guide on how to use the tool. It provides a step-by-step guide on how to run the OPT software, explanations of the sheets in OPT (OEE, OEE Table and Pain and Stop Table), definitions of the metrics displayed and examples of how to interpret the output values. The OPT Manual shall be used to facilitate the usage of OPT for both experienced users and beginners.

The OPT Manual can be viewed in full in Appendix VI.

OPT Meeting Procedure

The document called OPT Meeting Procedure proposes a structured method for holding a meeting focused on OPT. It is suggested that a meeting be held once a week to review and analyse the OPT outcome as well as to create actions to solve encountered issues and follow up on issued actions. A full OPT Meeting Procedure document has been developed and can be viewed in full in Appendix VII.

The steps of the OPT meeting are as follows:

1. Meeting Preparations
    a. Update OPT
    b. Review Action List from previous meeting
2. Start meeting with follow-ups of outstanding actions
    a. Go through issued actions
        i. If completed, fill in OPT Action List
        ii. If outstanding, refine action and/or update due date
3. Running OPT
    a. Review outcome
    b. Analyse outcome
    c. Use the 5 WHYs to find root causes of encountered issues
    d. Seek support in OPT Manual if needed
4. Fill in OPT Action List
    a. Add actions based on encountered issues to OPT Action List

OPT Action List

The OPT Action List is a document used to capture and keep track of actions formed by issues found when analysing the OPT output. A proposed OPT Action List design has been developed and can be viewed in full in Appendix VIII. The action list consists of the following categories to be filled in:

ACTION

- Action: Description of action to be taken

RACI responsibility roles

- Responsible: The person(s) working with achieving the task
- Accountable: The person answerable for the correct completion of the task
- Consulted: The person(s) to ask for advice in regards to the task
- Informed: The person(s) to keep informed

DATE

- Due date: When to be completed
- Completion date: Actual completion

OUTCOME

- Result: Result of action taken
- Conclusions: Conclusions that can be drawn from the action and its result. May result in a new action to be added to the OPT Action List

5.4 OEE FOR A GENERAL SINGLE STREAM PROCESS

Based on the general method of calculating OEE and the time definitions from the Anglo American Equipment Performance Metrics Time Model, a customised version has been developed in this Master's thesis project to better suit a general single stream process. However, this is not the method used in the developed tool, OPT. To view the OEE calculation model used in OPT, see 5.1.1 Final OEE Calculation.

The general quality calculation was customised to be valid for a single stream comminution process. Instead of using good pieces as a measure, the Master's thesis writers have developed a new method to calculate quality based on particle size. The Quality calculation is described in more detail in section 5.1.1 Final OEE Calculation.

$$Availability = \frac{Uptime}{Total\ Time} \qquad \text{Equation 21}$$

$$Performance = \frac{Actual\ Production / Target\ Rate}{Uptime} \qquad \text{Equation 22}$$

$$Quality = 1 - \frac{Mean\ deviation\ from\ Target\ Size}{Target\ Size} = 1 - \frac{\dfrac{\sum_{i=1}^{n}\left(Deviation\ from\ target\ size\right)_i}{n}}{Target\ Size} \qquad \text{Equation 23}$$

The general calculation of Availability was customised in order to better fit a single stream process. Instead of using Planned Production Time as the denominator in the general OEE definition, Total Time is used, which is the total hours available. The Availability is therefore determined by dividing the Uptime by the Total Time.

The general performance calculation had to be customised to be valid for a single stream process. Performance for a general single stream process can be calculated as stated in Equation 22. This gives in the ratio between the targeted time to produce the actual tonnes produced and the actual time consumed (uptime).

5.5 CRUSHER AND MILL STOPS REPORTING PROCEDURE

To enable the Pain Analysis to be performed, there is a need for daily reports of stops and their causes. There is a daily record of crusher and mill stops which is entered manually every morning. However, when this project started, the stop data was extracted into a report on a monthly basis, and its lead-time was longer than required.

This means that the required data to perform the Pain Analysis existed but a system to extract it daily was not in place and the data required a great deal of preparation to get it to a stage where it could be analysed. Therefore, a new system that allows all the crusher and mill stops data to be recorded and reported daily in electronic format has been developed and implemented at MNC by the Master's thesis writers. This procedure has eliminated the manual work involved when creating the crusher and mill stop reports and also reduced the risk for manual data entry errors. A map of the new procedure is presented in Figure 27 and can be compared to the former procedure found in section 4.4, Figure 4.

Beyond saving manual work, the procedure automatically allocates the lost time events to the time definitions presented in the Anglo American Equipment Performance Metrics, which facilitates the tracking of stoppages.

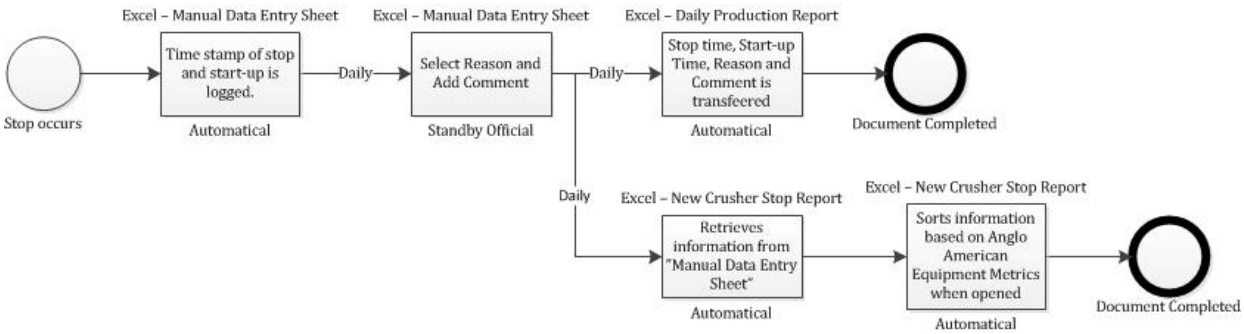


Figure 27 - New Crusher and Mill Stops Reporting Procedure Map

CHAPTER SIX

DISCUSSION & CONCLUSIONS

This chapter will discuss the findings of the project, drawn conclusions, answers to the research questions, observations and recommendations for the organisation are also presented and finally areas for future research are identified. The discussion and conclusions are presented in three distinct sections – Define, Develop and Design.

CHAPTER 6 - INTRODUCTION TO DISCUSSION

The mining industry has lagged behind manufacturing industry when it comes to process control and process optimisation. For instance, the mining industry does not use modern methods when it comes to measuring and calculating equipment performance metrics in an accurate way and using this information to monitor and improve processes. One of the goals in this project has been to use some of the knowledge from the manufacturing industry and apply it in the mining industry.

The discussion and conclusions are presented according to the three distinct project phases (see Figure 28). The initial challenge, as well as the first phase of this project, was to define an equipment performance calculation model for a single stream comminution process. The second phase of this project was to develop a tool (OPT) that uses the calculation model to perform real time calculations of OEE and other equipment performance metrics. The third phase was to develop a methodology describing how to use the tool output in the organisation in a value creating way, such as finding root causes to productivity limiting issues.

In the following sections a discussion on findings from the different phases of the project will be presented as well as conclusions drawn, answers to the research questions, observations, recommendations for the organisation and finally future research proposals.

6.1 CALCULATION MODEL

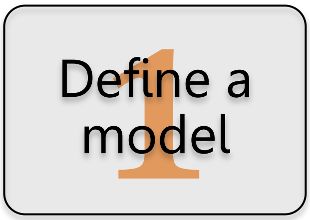


Figure 29 – Project phase one - Define

The baseline for developing the calculation model for OEE in a single stream comminution process was to make it as generic as possible and avoid making it site specific. During the pre-study in Sweden, the Master's thesis writers developed a functional method to calculate OEE in a single stream comminution process which was tested and validated by using historical production data from MNC. This was a good learning point which facilitated the understanding of the characteristics of the model and how certain parameters affect output.

Later, the Master's thesis writers were introduced to the Anglo American Equipment Performance Metrics, which is an internal company standard describing how to calculate equipment performance metrics including, for instance, OEE. The model developed by the Master's thesis writers was found to be well aligned with the company standard which is very good. The standard, however, was not comprehensive enough regarding quality definitions and calculations. Therefore, the quality definitions from the thesis writers' OEE model were adopted into the company's standard OEE definitions. The OEE model was continually under

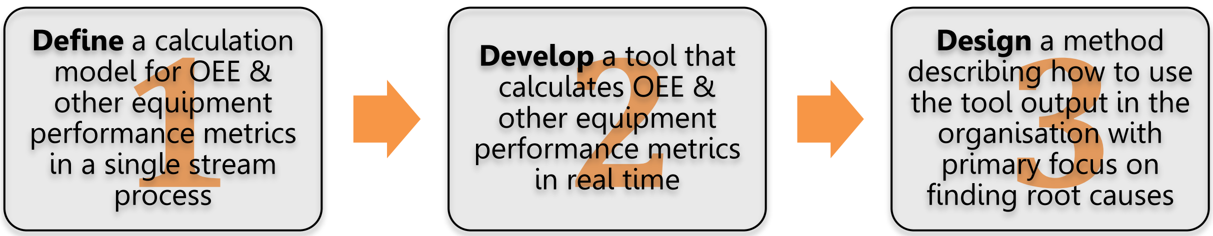


Figure 28 - Project phases

development during the project and as knowledge in the area grew, the model was refined and additional parameters were added.

OEE is a good performance measure, but it is important to not read it as one parameter; it is actually four. The individual parameters give a broader understanding of the equipment's performance and provide different approaches as to how the equipment's performance can be improved.

The downside of OEE is that it cannot provide the user with the reason for an eventual increase or decrease of the measure. It would of course be a great feature if the OEE could tell exactly what happened in the process, but that is not the character of the measure. This gap can be partially filled by using a systematic analysis method developed by the Master's thesis writers, discussed under section 6.3 OPT Method.

The fact that OEE already existed as an internal standard has only been beneficial for the project since it has created a smoother introduction of the OPT and its parameters. However, the OEE methods have not yet been fully implemented in the organisation and the OPT can act as a facilitator in the full implementation of OEE. In this way, OPT and the organisational OEE implementation can interact to create an OEE proficient organisation.

6.1.1 OEE Calculation

A unit's OEE can be determined by multiplying its Overall Utilisation, Performance and Quality (see Equation 24). The OEE is based on these three metrics, each one carrying the same weight, hence all are equally important when it comes to OEE. The OEE provides a good measure of the status of a unit; however, it cannot tell what causes the OEE number or how the OEE can be changed. By looking into the three included parameters, a slightly better view of the current unit status will be provided. Still, answers to possible issues will be hard to determine. To give a more inclusive picture of the unit status, two additional parameters are presented in OPT - Availability and Utilised Uptime.

Overall Utilisation

The metric Overall Utilisation shows the unit's time distribution as the percentage of time the unit is used for primary production. This is the metric which represents the time usage in OEE. However, it will not show the percentage of time the unit has been available for production, merely the time it has been utilised. By looking at the Overall Utilisation one cannot tell whether the unit has been utilised all the available time or if there is more available time to utilise. That is, one cannot tell if the available time has to be increased in order to increase the utilisation or if the utilisation can be increased without increasing the availability of the unit. To be able to determine this, OPT presents both Availability and Overall Utilisation (see section 6.1.2) for all possible units. Displaying of both the Overall Utilisation and the Availability facilitates the understanding of the distribution of the equipment's total time. To clarify the relation between Overall Utilisation and Availability, the Master's thesis writers defined a metric referred to as Utilised uptime (see section 6.1.3), which is the ratio between Overall Utilisation and Availability.

$$OEE = Availability \times Performance \times Quality \quad \text{Equation 24}$$

Due to lack of required data, it is not possible to determine Overall Utilisation for all units in the process. In those cases, Availability is being calculated instead. The user has to be aware that these two metrics differ and shall not be compared. The Availability can, however, be compared between similar units since it is being calculated for all units included in the project.

PERFORMANCE

The Performance of a unit has two components, Target Production Rate and Actual Production Rate, and is computed as the ratio between the two. This means that the Performance is as affected by the Actual rate as the Target rate. The Actual rate is determined by data extracted from the PI-database and is only dependant on the performance of the process unit. The Target rate is set by the organisation following certain guidelines (see section 5.1.6 Setting Filters & Target Values). This in turn means that a rate set by the organisation has a huge part in deciding the Performance rate of a unit. Therefore, the setting of the Target Production Rate needs to be done very carefully, otherwise Performance can turn out to be a misleading metric.

It should be noted that the Performance can result in a ratio greater than 100%. This will occur when the Actual Rate exceeds the Target Rate, which obviously happens when the Target Rate is defined at a too low value. In such a case the Target Rate shall be reviewed and possibly adjusted.

The Performance metric shows how efficiently the unit is working but will not show if the right things have been done, which is defined as effectiveness. The effectiveness has to be ensured by other organisational processes, such as quality assurance. The third metric in OEE provides a view of the quality of the performed work.

Due to lack of data, the Performance metric cannot be determined for all units. This is the case for all the classifiers, conveyors and feeders at MNC. From the available data one cannot tell the rate at which the units have been performing; hence, the Performance cannot be determined. For these units, the OEE will consist of Overall Utilisation and/or Availability. This is acceptable since the concerned units are not primary contributors to the main task of the production process – to comminute ore. Their main function can be regarded as supportive, therefore their main concern is to be available to perform their dedicated task.

QUALITY

The new definition of Quality (see Equation 25) combined with the method of how to, in practice, determine quality in a single stream comminution process has not been seen before. The development of a quality metric makes the OEE calculation complete and provides a more accurate OEE value than previously when the quality most often was assumed to be 100% in a process such as this one. It is a well-working method, however it could be refined. It does not take into account the magnitude of the deviations below target size but assumes all sizes below target to have a quality of 100%. The method could be refined to take those variations into account, which would result in a more accurate quality measure. At MNC, there was no need for lower particle size limits since all particles smaller than target size were accepted.

The method could also allow a certain span of sizes around the target size, if the unit would allow it. In this project, such defined parameters have not been found. The development of such target values should be the next step in improving the quality calculation.

According to the performed literature reviews, no way of determining quality in a comminution process has been previously defined. Normally the quality is assumed to be 100%. The Anglo American Equipment Performance Metrics quality measure provides a definition of quality (Equation 8) but no applicable definitions of the input values, i.e. Actual Size and Target Size. Therefore, the method developed by the Master's thesis writers to determine Quality (Equation 25) can be regarded as a major finding in this project. The developed quality measure gives the possibility to perform a more complete OEE for a comminution process, since there now exists a way to measure quality.

The Quality metric provides OEE an aspect of effectiveness – to what degree the right activities have been performed. If the particles are within accepted size, the right activities can be assumed to be performed. The other OEE parameters will then tell the amount of time the process needed to produce the output (Overall Utilisation) and at what rate the output was produced (Performance). If the Quality is not satisfactory, the unit is not performing the intended activities and the case has to be investigated. The Quality can be unsatisfactory due to, for example, improper equipment settings or unsatisfactory input to the unit. In a single stream process an unsatisfactory input can have a large impact on the output making it crucial to measure quality continuously in the process. However, since quality is monitored continuously in the process, the quality calculation assumes that the input is within the given target limits.

The Actual Particle Size input to the Quality calculation is extracted from the PI-database which stems from Particle Size Distribution curves. The curves are created with data from Lynxx cameras that optically determine the particle size distribution (PSD) of bulk material on a conveyor belt. The method provides a complete size distribution curve and the measure used in this calculation is P80. The cameras are installed at certain points in the process (see section 4.3.4 Lynxx Cameras and Appendix III). The usage of cameras to determine particle size is beneficial since it does not interfere with the process. The calculation uses the P80 size provided by the system and compares it with the target P80 size for that point in the process. That is, the Quality metric is fully dependant on correct data from the Lynxx cameras. If the data provided by the cameras is regarded to be accurate, the Quality metric also can be regarded as accurate. The accuracy of the camera data is ensured by regular calibration of the equipment and the Quality calculations can therefore be trusted.

The new definition is valid given that the required inputs are available. The input does not have to stem from Lynxx cameras; it can as well be drawn from any other reliable size measuring system. This widens the application of the model. However, a

$$Quality = 1 - \frac{Mean\ deviation\ from\ Target\ Size}{Target\ Size} =$$

$$= 1 - \frac{\dfrac{\sum_{i=1}^{n} \left(Deviation\ from\ target\ size\right)_i}{n}}{Target\ Size}$$

Equation 25

target size will always be required. In this case some of the target sizes for the process were already determined, others were not. At those points in the process where actual size is possible to determine, but the target size is undefined, a method should to be developed to determine the target size.

As previously mentioned, the Quality measure will not take the magnitude of the deviation below the target size into consideration. It will only take into account the percentage deviation above the target. This presentation of the number is chosen because all deviations below are regarded as positive. However, it is understood that the actual deviation is an important factor to consider. Therefore, in addition to displaying the quality, the tool displays the actual size deviation in millimetres including the sign of the value, plus or minus. Based on those two values the user of the tool can conclude how severe the deviation is. For instance, a negative deviation might be acceptable up to a certain limit, whilst all positive deviations might be unacceptable. This is a decision point in the tool where the user's expertise has to be utilised (see section 5.3.4 OPT Users).

Further, this method calculates the quality at given points in the process. For instance, for area 406, the quality is measured at the conveyor named 406-CV-007, which is the conveyor belt between the secondary screens and the mill feed silo. The actual size at that point is the result of the entire 406 circuit working together. Obviously, the HPGR crusher has alone reduced the size of the particles, which is the main task of the circuit. Still, all other equipment has to be in place and functional in order to bring the material through the circuit. The screens have to split the material accurately, the feeders have to feed, the conveyors have to transport and so forth. Therefore, the quality measured at 406-CV-007 is the quality of the product performed by the whole 406 circuit, not for any single piece of equipment. The same applies for the other process areas.

6.1.2 Availability

The Overall Utilisation is used as the main measure of time usage for a unit in the calculation model. However, if the Overall Utilisation equation for some reason is not applicable (e.g. lack of data), Availability is used. For units which lack the sufficient data one cannot tell whether the unit is performing primary production or not. Therefore, the metric Availability is being used in OPT for some classifiers, conveyors and feeders instead of Overall Utilisation.

Availability shows the ratio of time that the unit is available for production, i.e. the time it is not standing still and therefore has the possibility to contribute to the production process. However, the metric cannot provide information on the productivity of the equipment, which is presented through the metric Performance.

The Availability is also used as an additional parameter for the crushing unit in OPT. Displaying both the Overall Utilisation and the Availability facilitates the understanding of the distribution of the equipment's total time, since the two metrics use different parameters in their respective equations. What has to be considered is that in most instances the metric Availability will give a higher value than (or equal to) Overall Utilisation since the Uptime, which Availability is based on, is higher than (or equal to) the Primary Production, which Overall Utilisation is based on. This is because Uptime is more inclusive (also including for example idling time) than Primary Production (see Figure 10). This is important to regard when comparing the two metrics. It is always highly recommended to analyse the parameters included in a metric before comparing between metrics.

Availability is often used as an indication of how well maintenance work is carried out on an asset, i.e. how much of the total time the asset is available for production. However, efficiency of maintenance work is not the only factor affecting the available equipment time. At MNC, and in almost every single stream process, interlocks are used to control the process units' relative behaviour. This can result in, for instance, an upstream unit standing still due to a breakdown downstream. For this reason the analysis of available time has to take into account the reason for the downtime, which can sometimes be out of the control area of that certain unit.

6.1.3 Utilised Uptime

To clarify the relation between Overall Utilisation and Availability, the Master's thesis writers came up with a metric referred to as Utilised Uptime, which is the ratio between Overall Utilisation and Availability (see Equation 26). This ratio shows the percentage of the uptime that is used for primary production. The metric Utilised Uptime will highlight the difference between available time and utilised time, which is an unutilised time share and therefore an area of possible improvement.

Plants within the mining industry are often battling with trying to increase their equipment availability by improving the asset reliability and the maintenance quality. This is often done through the updating and changing of parts more frequently than required by the equipment condition, which often leads to high capital investments. During the Master's thesis writers time on site, the Utilised Uptime was frequently calculated and analysed and one important conclusion that could be drawn was that Availability is not a critical problem at MNC. The Utilised Uptime is most often low and primary focus should therefore be put on increasing the amount of primary production, hence the Overall Utilisation.

The Utilised Uptime metric can be used to read out various information about a unit. A low Utilised Uptime indicates a low utilisation of the time the unit actually has been available for production. This shows a possibility to increase the production of the unit by only increasing the utilised time, without increasing the available time of the unit or reducing the unit downtime. In fact, if the availability increases and the production time is constant, the Utilised Uptime will decrease. A Utilised Uptime of 100% indicates that all available time has been utilised for production. This means that both the available time and the utilised time have to be increased in order to increase production.

6.1.4 MTBF & MTTR

The two metrics Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) are two useful measures for indicating asset reliability and the quality of the maintenance work. Since they both represent a *mean time*, the metrics will give the average time between the failures and the average time to get the asset back in working condition. But none of the metrics will give the distribution of the failures or the time consumed to repair the unit. This is critical information for the

$$Utilised\ Uptime = \frac{Overall\ Utilisation}{Availability} \qquad \text{Equation 26}$$

site maintenance team in order to be able to improve their asset reliability as well as their routines. That is why MTBF and MTTR should be used as indicators trended over time together with a systematic analysis of the metrics, as discussed in section 6.3. Continuous logging of downtime, stop location, cause of downtime, etc. is important, not only to make it possible to calculate MTBF and MTTR but to also facilitate the analysis. This type of logging has been automated by the Master's thesis writers at MNC. Further details of the stop reporting procedure can be found in section 5.5 and 6.5.

The over-time trending of the metrics should be used when comparing the current status with previous results to understand if actions taken are improving the asset reliability and the quality of maintenance. The longer the time span reviewed, the more accurate the metrics will be. It is therefore preferable to analyse a time span of 30 days rather than 7 days.

6.1.6 Pain Analysis

The Pain analysis has been developed by the Master's thesis students. It provides the user with an understanding of the downtime situation and its distribution between total downtime and frequency or error. The usage of the Pain analysis saves the user the often complex task of combining frequency and downtime from two separate graphs to find the most critical error in the process.

It was discovered that frequency and total downtime of an error often do not correspond (see Figure 30). Sometimes the two parameters, rather, are inverted, i.e. when downtime is high, frequency is low and vice versa.

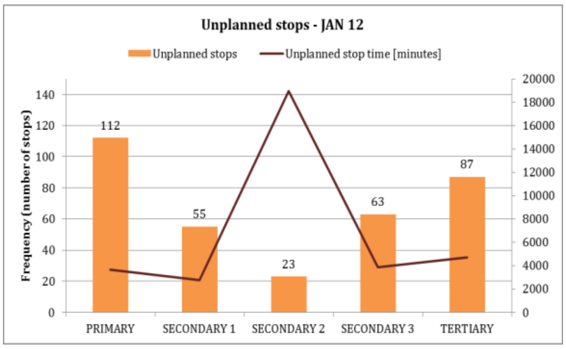


Figure 30 – The relationship between frequency and total downtime for unplanned stops in January 2012 at MNC

The Pain concept has been very well accepted, both on site and at the head office. The users highly appreciate the possibility to view frequency of error and downtime in one metric and one single diagram. The Pain concept as well as other parts of OPT will be implemented in newly developed software to be introduced company-wide. This can therefore be regarded as one of the major achievements in the project.

When introducing the new concept, Pain, it is important to clarify how the metric is computed so that no confusion arises. Most importantly, the Pain does not represent the total downtime in any sense but the product of frequency (n) and sum of downtimes, which makes Pain n times greater than the total downtime. To not confuse the user, Pain is presented as a unit-less metric.

The input to the Pain analysis is extracted from downtime reports which are performed only on crushing units; hence the Pain analysis is limited to those units. If a downtime reporting procedure would be in place for any other unit, a Pain analysis would be possible to perform for that unit.

Since the input to the analysis is drawn from downtime reports created by employees on site, the reporting has to be done properly. It is crucial that the reporting employee knows the process and what to report, i.e. the root-cause to the downtime and not the consequence of it. The human involvement will create a possibility of human errors in this otherwise highly automatic system. It has to be considered that errors can occur. To minimise errors in the reporting, the reporting employees shall be well educated. To ensure this, a workshop was held with the concerned parts on site.

The internal document, Anglo American Equipment Performance Metrics, not only includes OEE definitions but also downtime categorisation used to allocate downtimes and facilitate tracking and comparison between company sites. This categorisation model is included in OPT and in that way completely aligned with the company standard. The former reporting system was not aligned with the company standard and its downtime categories. The tracking was therefore not possible and has been made possible through the Pain analysis and OPT.

When comparing Pain values between units, one should be cautious and not compare different time spans since the values most often are higher for a longer time span. Also, caution has to be taken when determining an acceptable level for an error. For instance, the downtime named "Shift change" might always have the same, relatively high, level due to a predefined time dedicated for shift change and might therefore not need as much attention. Of course, the aim shall always be to decrease downtimes, but one should be aware that certain downtimes are more critical than others.

The Pain concept can be refined and developed by giving either component a factor to put more emphasis on it. This can be done if one of the components is found to be of more importance.

6.1.7 Setting Target Values

To enable some of the metrics to be calculated, target values need to be determined. This is the case when calculating Overall Utilisation. It has to be defined when the unit is performing primary production. For instance, a crusher might be defined to perform primary production when its power exceeds 140 kW. For other units, the limit can be defined as a speed or a weight etc. This concludes that the defined limit to a high degree decides the calculated equipment performance. Therefore it is highly important that accurate limits are defined. If so, the result will be truthful.

It is complex to set target values, especially as parameters are ever changing. According to the Master's thesis writers' proposal in section 5.1.6, it would be a good idea to set targets based on equipment changes. It is understood that small process equipment changes are being performed frequently and that targets cannot be changed as frequently, therefore, the suggestion is to review targets periodically. The user needs to find an appropriate interval to review the different targets, since it might not be suitable to review all targets simultaneously.

When targets are modified, the results will also change. For instance, if a unit is observed to always have high Performance, it performs close to its targeted rate, and a setting change is done to make it perform even better, the Performance value will most probably change. The user needs to be aware of this when changing targets and analysing data. This is particularly important when data prior to and after a target change is compared, since the results can change drastically when a target is changed.

In the end, it is highly recommended not to compare OEE values and the values of its included components between units and sites. If such comparisons are not being made, the exact numbers are not as important as the relative numbers for a single unit, which are of much more importance and interest. The handicap of a golfer can be used as an analogy when it comes to only competing and comparing results individually. Still, the ambition should always be to set as accurate target values as possible.

6.1.8 Equipment Classification

There are four different classifications of the equipment in the calculation model. The reasons for having different classifications of the equipment are two. Firstly, all equipment is not equally complex and does not require the same detailed monitoring. Secondly, all equipment does not have the same technical set-up and possibilities to measure all parameters. However, there will always be a demand for measuring all parameters for all units, but keeping the measures to a minimum reduces the risk for information overflow as well as makes it easier for the user to read the output from OPT. Full measures for all types of equipment would demand an investment as well since all equipment at MNC is not prepared with measuring equipment. The Master's thesis writers suggest that a proper evaluation should be performed to find out if there are any missing measure points before any investments are carried out.

Table 11 – Classification of equipment

Classification	**A**	**B**	**C**	**D**
Equipment	Circuits	Comminution units	Supporting equipment (with available measures)	Supporting equipment (without available measures)
Details	OEE Overall Utilisation Performance Quality Availability Utilised Uptime	OEE Overall Utilisation Performance Availability Utilised Uptime MTBF MTTR Pain	Overall Utilisation Availability Utilised Uptime	Availability

6.2 THE OVERALL PRODUCTIVITY TOOL (OPT)

Figure 31 – Project phase two - develop

During the early parts of the project, the Master's thesis writers developed a small scale OPT prototype to test the calculation model with production data from MNC. The idea of the OPT prototype was to learn as much as possible about the characteristics of the process and test the calculation model as well as the coding of the software. It was beneficial to run the calculation model at an early stage in the project since it gave the possibility to refine it and get feedback from the process reality. The learning curve was steep for the process knowledge but even steeper for the art of coding. Since the two Master's thesis writers are Mechanical engineering students and not Software engineering students. Throughout the project, the OPT prototype was constantly under development, where module after module was tested and added to the code. This gave a thorough understanding of the dynamics of the code. The coding could definitely have been done differently if it had been done by professionals from the beginning.

The overall concept is well aligned with the company standard of metric definitions, which helps to lower the learning curve for the user of the tool. OPT was developed with a product development approach and hence customised for the end users and their requirements.

At the end of the project the final OPT prototype, as well as the OPT guidelines and manual, were handed over to the end users so that they could start using OPT immediately. The tool has received very good feedback from the users at MNC as well as the senior team at the Head Office in Johannesburg. The plan is for MNC to use the OPT prototype and provide feedback to the process control team in Johannesburg, which is currently working on a new software platform that will use some parts of OPT. The fact that Anglo Platinum will use parts of the project proves that the outcome is practically useful. Hopefully, this project will fill an existing gap in the productivity improvement work within the organisation.

The development of a suitable way to present the OPT output has been a long iteration process. It was a balancing act to keep it simple and clean while still providing the user with enough, and the right, information to enable the user to perform an analysis and make accurate and valuable conclusions. There is an infinite amount of information that could be presented in OPT, but the Master's thesis writers have been very selective in the decision on what to present and what to leave out. The information in OPT is presented on two different ways - overview graphs and detailed data. The overview graphs are to be used to get a quick overview over the current status, while the detailed data can be used for more detailed systematic analysis. This applies to all the metrics in OPT, i.e. OEE, Availability, Utilised Uptime, MTBF & MTTR as well as Pain analysis. The presentation of data in OPT is consistent, which is important since it speeds up the user learning curve as well as facilitates the analysis of large amounts of data.

OPT is built in Visual Basic Editor and the user interface is Microsoft Excel. There are several benefits from this. OPT extracts data from the process database PI and performs calculations according to the calculation model and presents the results in Microsoft Excel automatically. Microsoft Excel is a very common software, which means that most of the users already are familiar with the interface and are capable of using OPT. It will be easy for the more advanced users to make changes and amendments to the code, but this has been restricted to only certain users to avoid mistakes and corruption of data. For MNC, the use of OPT will not incorporate any investments since Microsoft Excel is already a part of the company software package.

The dry section at MNC consists of five production areas, 102, 401, 405, 406 and 407. All these areas are covered by OPT to get a comprehensive view of the dry sections productivity. OPT can be extended to cover all process areas at MNC to get an aggregate view.

6.3 OPT METHOD

The OPT method is based on three parts, User expertise, the 5 Why's and the OPT guidelines. They found the basis for how OPT should be utilised to gain as much valuable output from it as possible.

Figure 32 – Project phase three - design

The OPT users' background knowledge of the process is the key to understanding the information presented in OPT. It has been assured that the intended users of OPT at MNC have the required knowledge. If this requirement is not met by the user, the result will most certainly not be as satisfying as is could be.

The Five Why's is an internationally recognized systematic problem solving methodology that has a proven record of finding root causes. The Five Why's is already implemented in the organization as the main problem solving methodology. It has therefore been incorporated in the OPT method.

To further facilitate ease of use for the users of OPT, the Master's thesis writers have developed structured guidelines to follow when working with OPT. The guidelines consist of three parts; the OPT Manual, the OPT Meeting procedure and the OPT Action list. The OPT Manual is a complete guide on how to use the tool with examples of how to interpret various results. The OPT Meeting procedure proposes a structured way of holding a meeting focused on OPT and its outcome. The OPT Action list is a document to capture and keep track of actions that have evolved from analysing the OPT output.

The OPT Manual will most likely be used during the introduction period of OPT. The manual is a good guide for someone who has not previously worked with OPT and therefore is not familiar with all the metrics. The manual should also be used whenever a new problem is detected since it addresses different ways to interpret OPT output. However, OPT is developed to be so user-friendly and intuitive that no manual is necessary, so the intention is that the manual should not be needed constantly.

The meeting procedure document was developed to create a focused meeting with the aim to analyse and find root causes to problems as well as follow up on issued actions. The predefined procedure will hopefully guide the meeting participants through the meeting and help to keep the meeting productive and not too time consuming.

The main reason for using an action list as a supportive technique when working with the tool is that the actions shall be documented and it should be stated who is responsible for what. The emphasis should be put on analysis of outcome and follow-up of actions taken, since those two areas tend to sometimes be neglected at MNC.

When OPT and the OPT Guidelines were handed over to the organisation, the manual incorporated in the guidelines was highly appreciated by the organisation, since the Master's thesis writers were leaving the site upon project finalisation. The users now have the possibility to further train themselves in using OPT as well as to train new users. It will also work as a support if something with OPT is not working properly.

There will always be a need to analyse the OPT outcome since merely reading the numbers cannot provide any complete answer. The goal with the OPT analysis is to identify and eliminate root-causes to encountered problems that affect the productivity. The analysis of metrics displayed in OPT are suggested to be carried out in two major ways and can be summarised as follow:

1. From metrics to process. If there is noticeable change in metric values, find reasons in the process.
2. From process to metrics. If certain changes are being performed in the process, investigate if the metric values are changing.

The end users were identified during the time at MNC and the reason for using them is their good process knowledge as well as their cross functional positions where they can exchange valuable information between their respective departments. The employees chosen to be the main users of OPT belong to the engineering and technical teams. This is considered to be a successful combination of users since skills from different departments are important for getting everyone focused on the most critical problems. The cross functional collaboration around the tool will hopefully help to increase the general cross functional collaboration in the organisation. It has been observed by the Master's thesis writers that an increased cross functional collaboration is possible and is therefore advisable. An improved cross functional collaboration will create a common focus in the organisation and help the employees to reach their goals and at the same time reduce the risk for dual work.

What has not been done is a proper test and evaluation period, similar to what was carried out for the calculation model and tool. This is currently carried out by the organisation itself and the end users of OPT. A proposal for an evaluation project by the Master's thesis writers is under development.

6.4 OEE FOR A GENERAL SINGLE STREAM PROCESS

During the pre-study, the Master's thesis writers developed a general model for calculating OEE in a single stream process. The aim was to keep the model separated from a specific site or company. The process to develop the model gave good knowledge in the subject, which helped later during the development of the final calculation model customised for MNC. The general model has not been used in OPT because the organisation standards had to be considered. However, the Quality calculation developed by the Master's thesis writers is used both in OPT and in the general calculation model since there was a gap in the definitions created by the organisation, which prevented the use of the proposed Quality definition.

The model suitable for a general single stream process was tested on historical data and was found to be working very well. It would be interesting to test it in another single stream process, for example in a different industry such as the paper and pulp industry.

6.5 CRUSHER AND MILL STOP REPORTING PROCEDURE

The new automatic stop reporting procedure developed by the Master's thesis writers has created a way for the downtimes to be allocated and categorised according to the Anglo American Equipment Performance Metrics downtime categories. This facilitates tracking and comparison of downtimes between company sites, which is important in large businesses.

Beyond the company-wide standardisation benefits, it also facilitates the analysis of downtimes and errors on site since the reporting is being performed daily, instead of once a month as before. This shortening of lead-time has resulted in a process where downtimes can be investigated very soon after their occurrence which helps minimise their negative impact on the process.

Previously, the downtime table was created by manually entering downtime information and manually categorising the downtimes. In the new procedure, a script draws data from the PI-database and organises it into a downtime table. The new downtime reporting procedure can be argued to be more robust since it has eliminated several manual steps.

6.6 RESEARCH QUESTIONS AND ANSWERS

This section will present the answers to the Research Questions.

1. *How can a method be developed to define and rank process units critical to productivity in a comminution process?*

   Firstly, the process needs to be completely understood by the person developing the method. Both inter-process relations and individual unit functions have to be mapped and comprehended. This should be done in order to identify critical parts of the process.

   Secondly, there is a need for a thorough understanding of the organisation running the operations.

   Thirdly, a measure of productivity has to be defined in order to be able to evaluate the productivity of the process units. OEE (Overall Equipment Effectiveness) is such a measure. It gives an inclusive view of the value added by the unit since it includes three measures (availability, performance and quality).

   Fourthly, which units to include in the ranking need to be defined. The selection of units can be done based on the knowledge assimilated in the previous steps.

   Fifthly, based on the understanding of the operations, critical process parameters have to be determined. Every single unit within a comminution process has certain parameters to address when looking at productivity. Among those parameters, some are more critical to productivity than others. These have to be identified and will be used further on in the ranking.

Sixthly, a rating based on the critical parameters should be developed. The rating has to take in to account the different criticality of the parameters. For instance, safety shall have the highest criticality among the parameters.

To keep the method aligned with the current operations the parameters within it need to be periodically reevaluated.

2. *How should OEE numbers be calculated in a comminution process?*

   The traditional OEE calculation was developed for the manufacturing industry and is therefore not suitable for a comminution process. Several changes have to be made to suit a comminution process. The calculation model developed to suit this particular process is presented in section 5.4 OEE for a General Single Stream Process. Given that the required data is available, this method should be suitable in a general case. The major difference from the general OEE calculation is the new way to define Quality, which is customised for a comminution process.

3. *Which factors in the process chain are more critical to productivity – according to the OEE method?*

   To achieve a high OEE, the included metrics must all be high. Overall Utilisation will be maximised when the unit has a high running ratio, i.e. few stops. This will be facilitated by the good condition of the unit, which can be assured through high quality maintenance.

   The Performance will be maximised when the unit is running better than, or as close to its target rate, as possible. To achieve this the unit has to receive a satisfactory and continuous feed, run with optimal settings and be in good condition.

   The Quality will be maximised when the unit is producing the right particle size, i.e. minimising the deviation from target size. The actual particle size will be dependent upon the quality of the feed, the settings of the unit and the condition of the unit.

4. *How can OEE be used as a performance measure of equipment and process performance?*

   Since OEE includes three measures, i.e. availability, performance and quality, it is a comprehensive performance measure in comparison to single-parameter measures.

   It is highly important that the target KPI of each unit is established based on the conditions of that particular unit and that the targets are being reviewed on a regular basis. It is important to note that the OEE of a unit shall not be compared to OEE's of other units, but only to itself. This is crucial since the conditions and target definitions between units may differ.

5. *How can a high OEE help to improve SHE (Safety, Hygiene, Environment)?*

   High OEE measures imply a well running plant. This facilitates the planning of scheduled stops and most definitely results in fewer breakdowns. A process with few unscheduled stops, i.e. a large proportion of scheduled stops, is a safer process than a process with a large amount of unscheduled stops. This is the case since scheduled maintenance gives the opportunity to plan the maintenance actions and creates better conditions for the performance of safe operations. Hence, a high OEE creates opportunities to improve SHE.

6. *How can measuring OEE help to improve productivity?*

   The measuring will not improve productivity directly but measuring individual OEE's of the units in the process will help to identify where in the process bottlenecks exist and will therefore highlight possibilities for improvement. A successful elimination of the identified bottlenecks will result in an improvement in OEE and can consequentially give a productivity improvement.

6.7 OBSERVATIONS

One of the reasons for spending a considerable period of time on site was for the researchers to observe the day-to-day activities and gain a greater understanding of the operations. Various observations have been made during the time spent on site. Only those that were deemed important for plant productivity are reported here.

PROBLEM SOLVING

Observations have been made regarding the problem solving procedures in the operations. Although many tasks in the operations involve problem solving, there seem to be no defined structure and documentation of procedures used in recurring tasks. Granted, while most of the employees have many years of experience, the procedure followed in problem solving processes cannot be refined or improved when evaluated because there is no proper documentation. In addition to this, it is difficult to train new people because there is no database with information on the problems encountered in the plant and how they were resolved in the process. For instance, the 5 WHYs method is frequently mentioned as the correct method to follow, however, no documentation has been presented on how it had been used to resolve problems on the plant. From the outsider- it does not seem to be used to the same extent as planned.

Clear problem solving procedures should be developed and communicated to the employees who are intended to master and apply the methods. In cases where education is required to use the methods, a concerted effort should be applied to provide it. The existing problem solving method (the 5 WHYs) is a suitable method which can help to eliminate root causes. A proper follow-up of the usage of the communicated method should be done.

FOLLOW-UP

The plant has done well in following up on most of the issues that have arisen. It is commendable for a plant with such a large capacity to carry out most of the follow-up tasks as they do. However, the documentation and formal report back on the actual effects of performed process changes targeted for follow-up on tasks that need a review is not stringent. This leads to failure to attend to some of the cases targeted for follow-up. If the records and report backs do not capture the follow-up information and the effects of the change, the plant would take it for granted that follow-ups are done continuously even though some of the key matters are not getting any attention. This can be the case for some major process changes such as changing the liner in a crusher or adjusting the crusher gap settings.

The responsibility for follow up should be shared throughout the entire organisation. When a particular recommendation for process changes is made, a person should be assigned to implement proper evaluation and follow-up. This will make it easy for all involved to understand the effects of process change

Follow-ups are not only important after major process changes, but also for regular tasks assigned to people. These can be listed as action items for weekly meetings and the tick box approach can be taken at such meetings. This should be done to capture a record which may be very useful in providing insight on jobs that take a long time and the reasons for such delays which can feed directly into planning meetings. Such a record can also provide information on problematic areas of the plant which may require more resources with time. This can result in a better understanding of recurring tasks as well as a learning opportunity for the other meeting participants.

INTER-DIVISIONAL COMMUNICATION & COOPERATION

Throughout the organisation there is a common drive to produce concentrate as effectively as possible and to maintain the plant in a good operational state. This is clearly visible even for external observers like the researchers who prepared this report. However, the plant is fairly large and it takes a long time for information to reach all the relevant people in various sections of the operations. There is an opportunity to implement information structures that can help visualise information between divisions of the operation. This will also reduce duplication of efforts because the divisions will have a better insight into the activities taking place in other divisions at the same time. Further, it will work as a learning opportunity for the persons not directly involved but well informed. In that way they can gain a greater understanding of the work of other divisions.

Although a lot has been done to promote communication and cooperation there is still a divide between divisions. There is still a divide in reporting structures and development of tasks which leads to duplicated efforts. The communication and cooperation between divisions should be enhanced and the duplicated efforts should be eliminated. This can be done by, for instance, holding common meetings involving only the people relevant for the discussion. It is recommended to keep the meetings action oriented and focused on the dedicated subject in order to optimise the numbers of persons involved and to minimise time spent on meetings.

JOB CARDS

The current system for maintenance relies on the SAP to generate job cards which in most cases works well. However, some areas in the process do not have access to job cards because some tasks lack a dedicated functional code in the system. The problem that arises from this is that some jobs are performed without job cards and therefore cannot be easily tracked. Further, all existing job cards should be continuously reviewed to keep them aligned with the continuously changing process.

GOVERNANCE

MNC has a defined structure in terms of the sections of engineering, technical/metallurgy and production which is commendable. It is also evident that when repair work is required, teams from all sections are involved, which reinforces the team spirit that is present at the concentrator. However, it has been observed that due to the integration between those teams, some areas of responsibility for certain categories of employees seem to be undefined. In a case when a task does not require handling in a routine manner, it can easily fall under no one's area of responsibility and this can create a problem. A good example of this would be equipment failure due to an unidentified problem. In this case it is better for the maintenance division to focus on the required repair work, while production teams continue with production tasks. This will minimise the impact of the repair work on production and will also ensure that the responsibilities for various tasks are streamlined. It will also assist in eliminating duplication of efforts on the same task. This mode of operation can only be achieved if all the sections have full staff complements and all the teams are skilled in specific tasks. It also requires a common decision making platform and approach.

UTILISING OPT IN THE ORGANISATION

In addition to the suggested general improvements, a new weekly meeting should be initiated; this should involve key people from all divisions. The cross-divisional meeting participants should use the tool developed in this Master's thesis to create a continuous improvement forum. This will allow plant personnel more opportunities to communicate and resolve plant communication problems seamlessly. Having cross-divisional participants in the meetings when applying the tool will provide a good platform for tracking and learning from actions taken which will lead to an increase in productivity.

The outputs from the tool can help create standards which can be formulated and implemented in the organisation. Follow-ups on matters arising from using the tool can be structured and implemented with buy-in from all divisions.

6.8 RECOMMENDATIONS

Recommendations for the outcome of this project mainly concern the usage and future development of the Overall Productivity Tool (OPT). The development of OPT should continue before the new platform is completed, it is highly recommended that the current users of OPT continue to provide feedback on how the tool is used and how it can be improved by suggestions for improvements can be incorporated in the follow up version. The users are encouraged to thoroughly test the different methods suggested by the Master's thesis writers since these have not been fully evaluated on a production plant. Another important aspect of the methods is that they should be tested by several different users and not only the main users to provide information on how user friendly the tool is. It is crucial to do this in order to receive feedback from experienced, as well as new, users before further development options proposed.

6.9 FUTURE RESEARCH

The Master's thesis writers have found many interesting areas of research and would like to propose a few subjects for future research.

- Evaluate and develop the methods suggested in phase three of this project since this has not been done in the project due to the limited available time.

- The setup for OPT in its current form focuses on the comminution areas of MNC. It is suggested that OPT should be extended to all process areas at MNC.
- The calculation model could be tested in a different industry such as the paper and pulp industry or in a single stream manufacturing plant.
- The financial benefits of OEE and other performance metric improvements is an area where detailed research is proposed. More detailed background information on this would be beneficial for an organisation when deciding what investments to make in order to improve process productivity.
- The authors of this Master's thesis have seen that it would be possible and beneficial to integrate OPT with a condition measurement system. This can increase the maintenance quality in the process which is beneficial for improving productivity.

REFERENCES

Ahlmann, H., (2002). *From traditional practice to the new understanding: the significance of the Life Cycle Profit concept in the management of industrial enterprises.* In: IFRIM (International Foundation for Research in Maintenance), Maintenance Management & Modelling conference. Växjö 2002, Växjö, Sweden: International Foundation for Research in Maintenance

Anglo Platinium webpage (updated 2011), *About Anglo Platinum* (Electronic). Available at: http://www.angloplatinum.com/about/about_sub/comp_profile.asp [Accessed August 15, 2012]

Bryman, A., and Bell, E., (2011). *Business Research Methods* (3rd ed.). Oxford: Oxford University Press.

Crundwell, F., Moats, M., Ramachandran, V., Robinson, T., Davenport, W.G., (2011), *"Extractive Metallurgy of Nickel, Cobalt and Platinum Group Metals"*, Elsevier, ISBN 978-0-08096-809-4

Dressler, S., (2004), *Strategy, Organization and Performance Management. From Basics to Best Practices,* Universal-Publishers, ISBN 978-1-58112-532-0

Gulati, R., (2009), *Maintenance and Reliability Best Practices,* Industrial Press, Inc., ISBN: 978-0-83112-211-5

Halachmi, A., "Introduction—Performance Measurement is Only One Way of Managing Performance" *International Journal of Productivity and Performance Management: Performance Measurement and Performance Management, Volume 54, Number 7, 2005*. Emerald Group Publishing 2005. http://common.books24x7.com.proxy.lib.chalmers.se/toc.aspx?bookid=13077 [Accessed November 2, 2012]

Hansen, R C., (2001). *Overall Equipment Effectiveness A Powerful Production / Maintenance Tool for Increased Profits*. New York, Industrial Press, Inc. ISBN 0-8311-3138-1

Idhammar Systems Ltd., (2010), *Implementing OEE Systems*. [online] Bristol: Idhammar Systems Ltd., Available at: http://www.idhammarsystems.com/resource%20library/overview/whitepapers/ [Accessed September 13, 2012]

Kato, I. and Smalley, A., (2011), *Toyota Kaizen Methods: Six Steps to Improvement*. Taylor and Francis Group, Productivity Press. ISBN: 978-1-4398-3854-9

Kitco webpage (updated 2012), *Live Charts* (Electronic), Available at: http://www.kitco.com/charts/livegold.html [Accessed October 25, 2012]

Lesshammar, M., (1999), "Evaluation and improvement of manufacturing performance measurement systems – the role of OEE", *International Journal of Operations and Production Management*, vol. 19, no. 1, pp. 55-78

Liker, J. K. and Convis, G. L., (2012). *The Toyota Way to Lean Leadership: Achieving and Sustaining Excellence through Leadership Development*. McGraw-Hill. ISBN: 9780071780780

REFERENCES

Liker, J. K., and Franz, J. K., (2011), *The Toyota Way to Continuous Improvement: Linking Strategy and Operational Excellence to Achieve Superior Performance*. McGraw-Hill USA. ISBN: 978-0-07-176215-1

Ljungberg, Ö., (2000), *TPM Vägen till ständiga förbättringar.* Lund: Studentlitteratur. ISBN: 978-91-44-00837-0

Luotojarvi, M., 2009-04-09, *Method and a system for improving the operability of a production plant*, US 2009/00940880 A1, United States of America.

Mahadevan, B., (2009), *Operation Management: Theory and Practice*, Prentice Hall, ISBN: 978-8-17758-564-3

Mail & Guardian webpage (updated 2011), *Platinum's pluses and minuses* (Electronic), Available at: http://mg.co.za/article/2011-11-25-platinums-pluses-and-minuses [Accessed October 25, 2012]

Maran M., Manikandan G., and Thiagarajan, K., (2012). Overall Equipment Effectiveness Measurement By Weighted Approach Method. In: IMECS (International MultiConference of Engineers and Computer Scientists), *International MultiConference of Engineers and Computer Scientists 2012*. Hong Kong, 14-16 March 2012.

Merriam-Webster, *Opt – Definition* (Electronic) Available at: http://www.merriam-webster.com/dictionary/opt [Accessed November 30, 2012]

Mining Weekly webpage (updated March 14, 2008), *Biggest platinum concentrator achieves safety milestone at PPRust*, Available at: http://www.miningweekly.com/article/biggest-platinum-concentrator-achieves-safety-milestone-at-pprust-2008-03-14 [Accessed November 30, 2012]

Nadler, D, Tushman, M., (1997) *Implementing New Designs: Managing Organisational Change.* Managing Strategic Innovation and Change: A collection of readings, First edition, pp 596-606. Oxford University Press, New York.

Nakajima, S., (1989). *Introduction to TPM.* Cambridge, Mass.: Productivity Press

Oxford Dictionaries, *Definition of comminution* (Electronic) Available at: http://oxforddictionaries.com/definition/english/comminution [Accessed November 30, 2012]

Oxford Dictionaries, *Definition of kaizen* (Electronic) Available at: http://oxforddictionaries.com/definition/english/kaizen [Accessed December 11, 2012]

Perrin, R., (2008), *Real World Project Management: Beyond Conventional Wisdom, Best Practices and Project Methodologies*, John Wiley & Sons, ISBN: 9780470170793

The PGM Database, *Metals Data* (Electronic) Available at: http://www.pgmdatabase.com/jmpgm/index.jsp [Accessed August 15, 2012]

Probert, T., (2011). Rocking around the clock in SA. *African Review of Business and Technology*, February 2012, pp.56-57.

Platinum Today webpage (updated 2012), *Properties of platinum group metals* (Electronic), Available at: http://www.platinum.matthey.com/applications/properties-of-pgm/ (2012-08-15)

Prokopenko, J., (1987). *Productivity management: A practical handbook*. International Labour Office, ISBN: 92-2-105901-4

Rich, N., Esain, A., Bateman, N., Massey, L., Samuel, D., (2006). *Lean Evolution: Lessons from the Workplace*. Cambridge University Press.

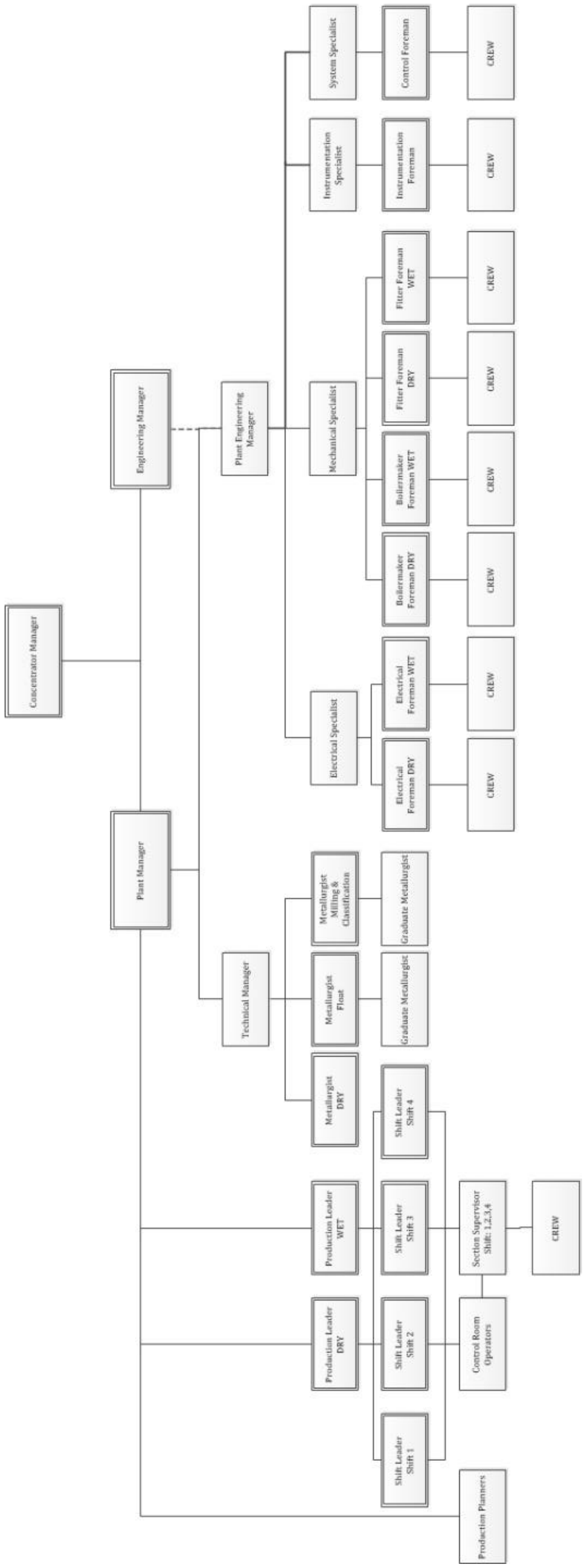
Scheinberg, S. (2009). "*From Inner to Outer Integration of Refugees and Immigrants in the Swedish Society: A Gestalt Intervention*" in Joseph Melnick and Edvin C. Nevis eds. Mending the World: Social Healing Interventions by Gestalt Practitioners Worldwide, A Gestalt International Study Center Publication, p. 206-240

Smith, R. and Hawkins, B., (2004). *Lean Maintenance*, Butterworth Heinemann ISBN: 978-0-7506-7779-0

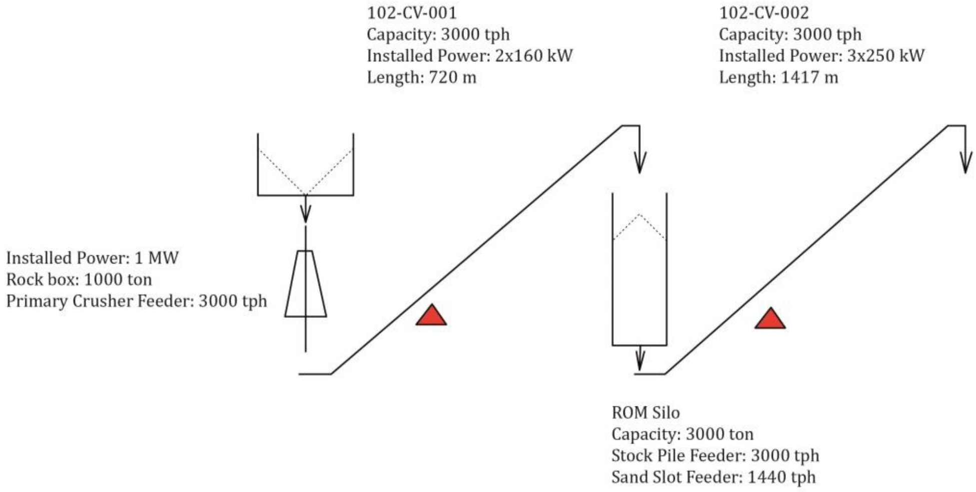
Strauss, A., and Corbin J.M., (1998). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks, California: Sage.

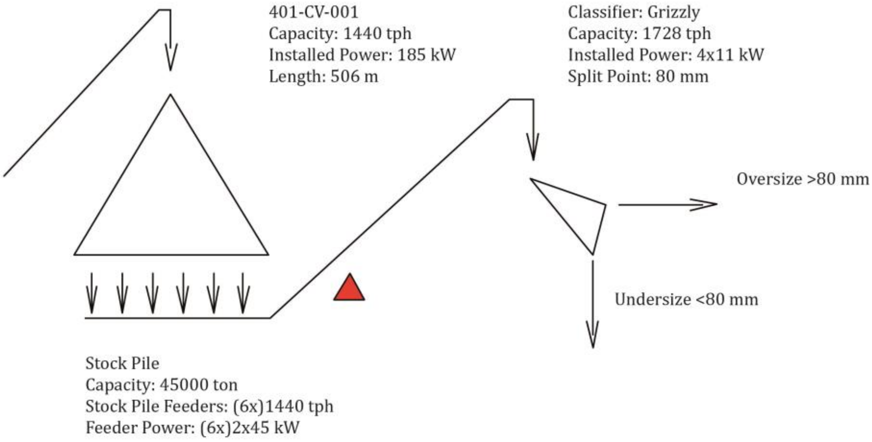
Taylor Fitz-Gibbon, C., (1990). "*Performance indicators*", BERA Dialogues (2), ISBN 978-1-85359-092-4

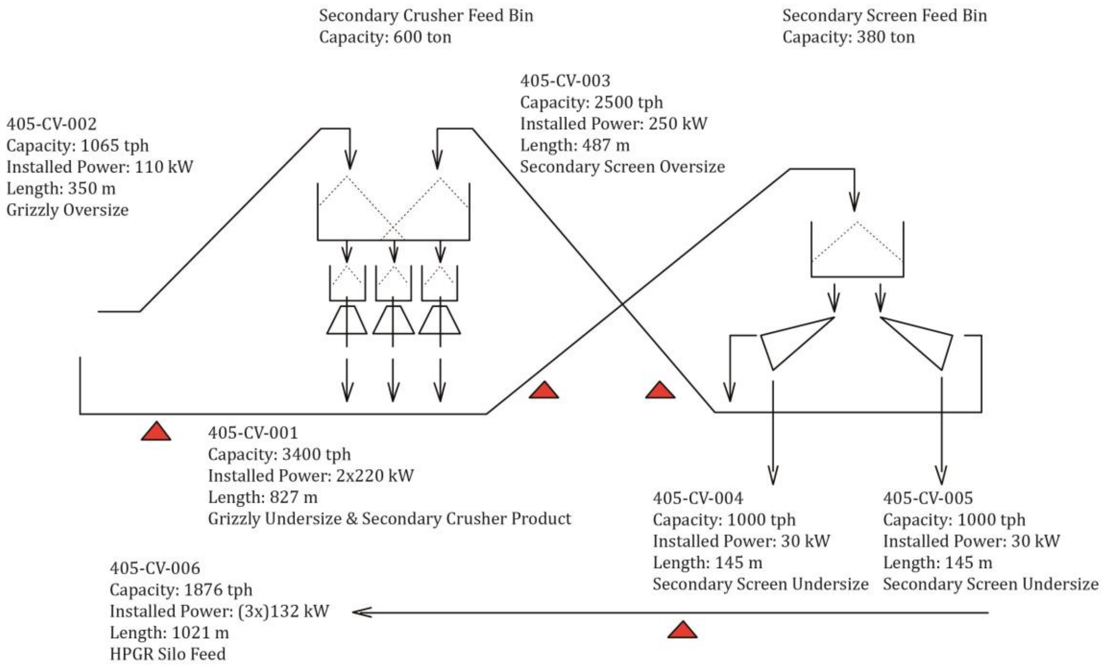
APPENDIX I - ORGANISATIONAL CHART

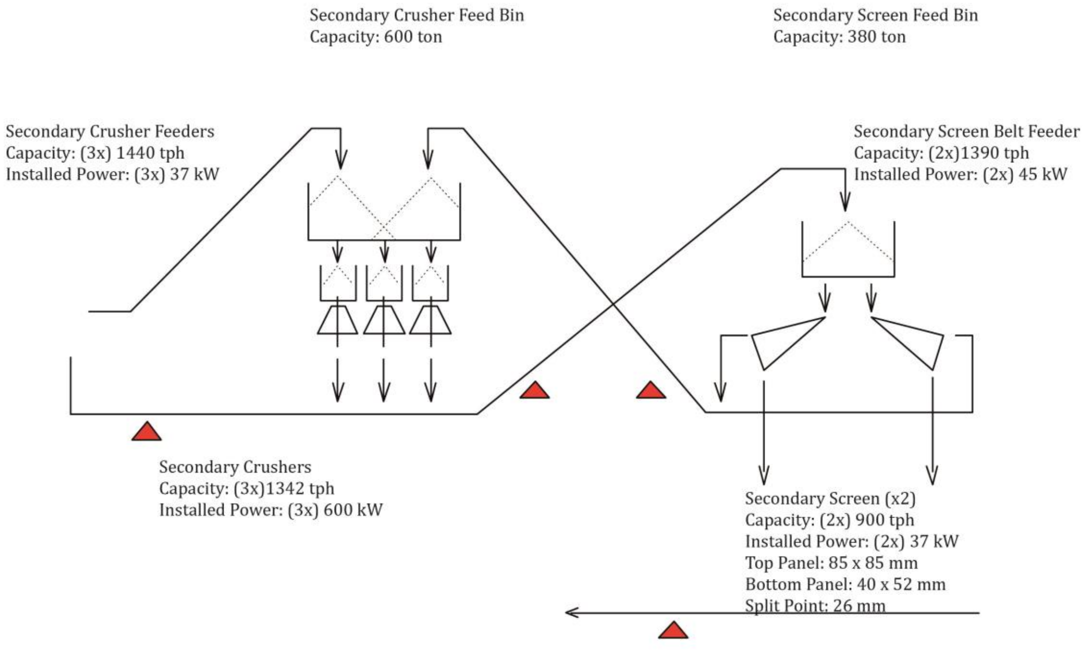


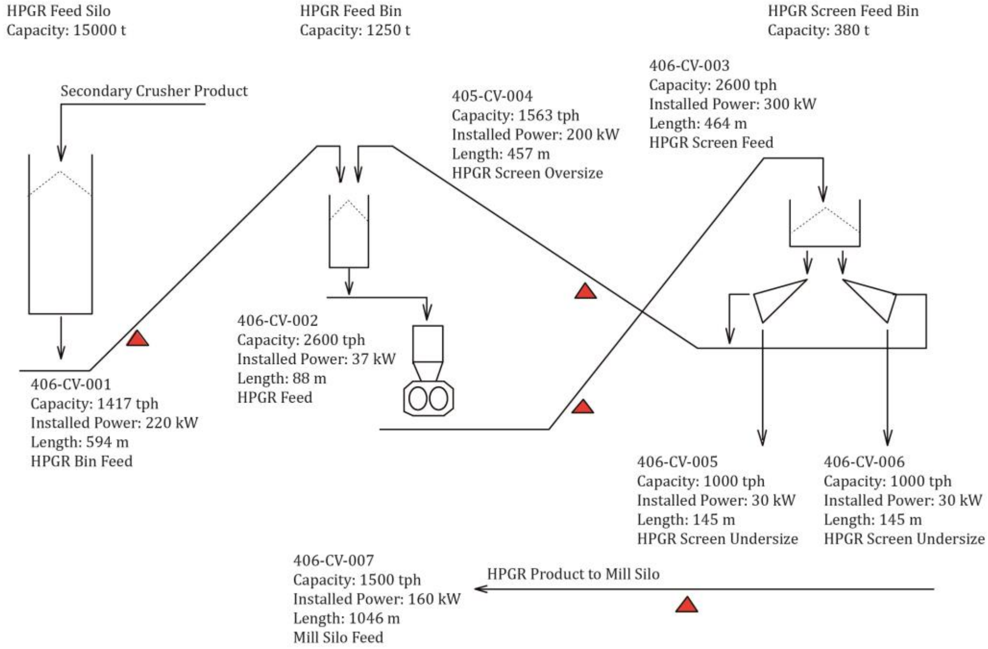
APPENDIX II - PROCESS MAPS

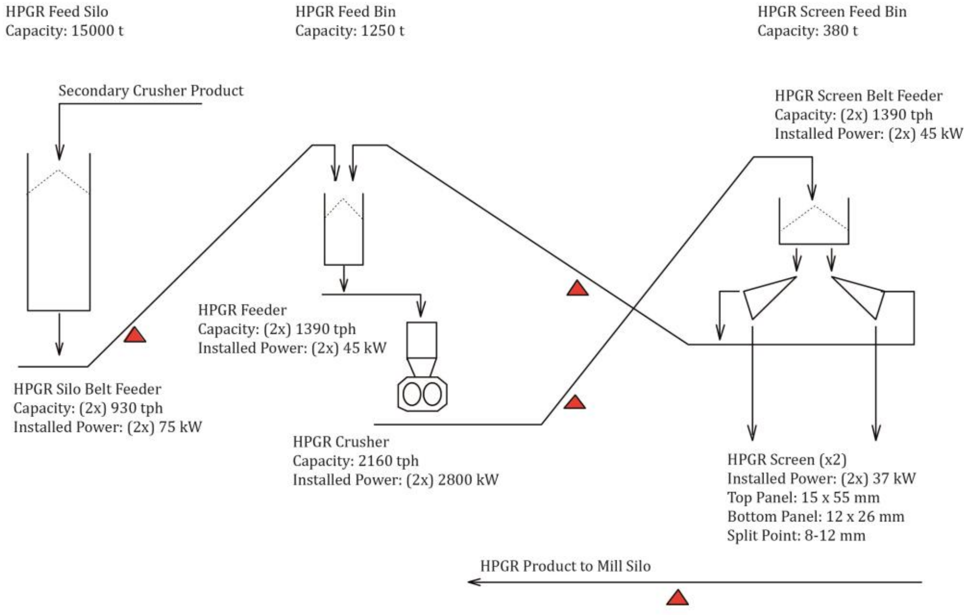


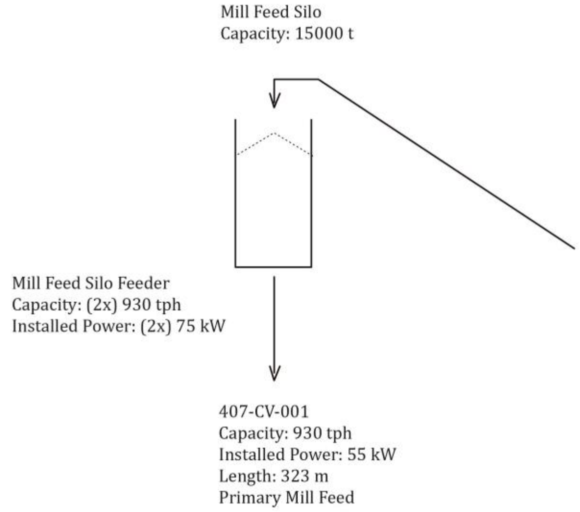


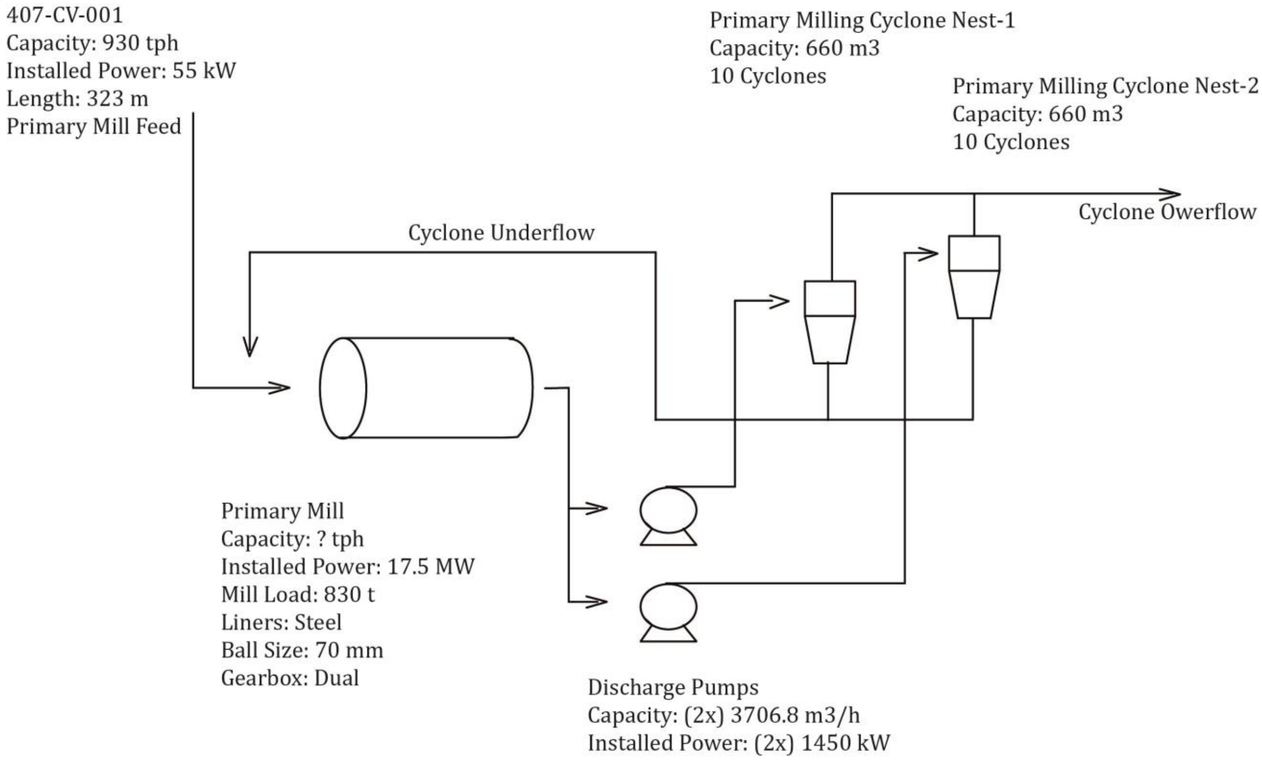

Secondary Crusher Feed Bin
Capacity: 600 ton
Secondary Screen Feed Bin
Capacity: 380 ton
405-CV-003
Capacity: 2500 tph
Installed Power: 250 kW
Length: 487 m
Secondary Screen Oversize
405-CV-002
Capacity: 1065 tph
Installed Power: 110 kW
Length: 350 m
Grizzly Oversize
405-CV-001
Capacity: 3400 tph
Installed Power: 2x220 kW
Length: 827 m
Grizzly Undersize & Secondary Crusher Product
405-CV-004
Capacity: 1000 tph
Installed Power: 30 kW
Length: 145 m
Secondary Screen Undersize
405-CV-005
Capacity: 1000 tph
Installed Power: 30 kW
Length: 145 m
Secondary Screen Undersize
405-CV-006
Capacity: 1876 tph
Installed Power: (3x)132 kW
Length: 1021 m
HPGR Silo Feed

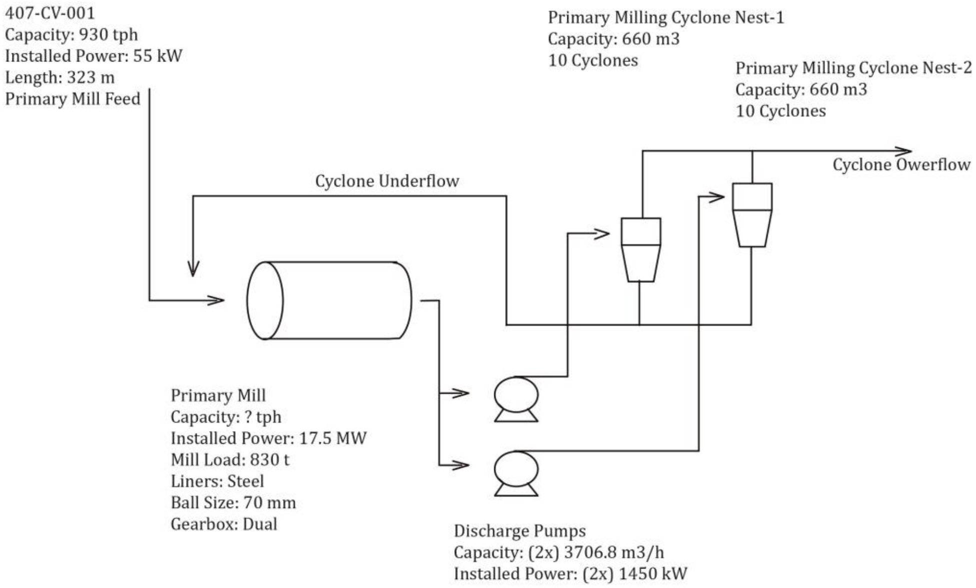

Secondary Crusher Feed Bin
Capacity: 600 ton
Secondary Screen Feed Bin
Capacity: 380 ton
Secondary Crusher Feeders
Capacity: (3x) 1440 tph
Installed Power: (3x) 37 kW
Secondary Screen Belt Feeder
Capacity: (2x)1390 tph
Installed Power: (2x) 45 kW
Secondary Crushers
Capacity: (3x)1342 tph
Installed Power: (3x) 600 kW
Secondary Screen (x2)
Capacity: (2x) 900 tph
Installed Power: (2x) 37 kW
Top Panel: 85 x 85 mm
Bottom Panel: 40 x 52 mm
Split Point: 26 mm

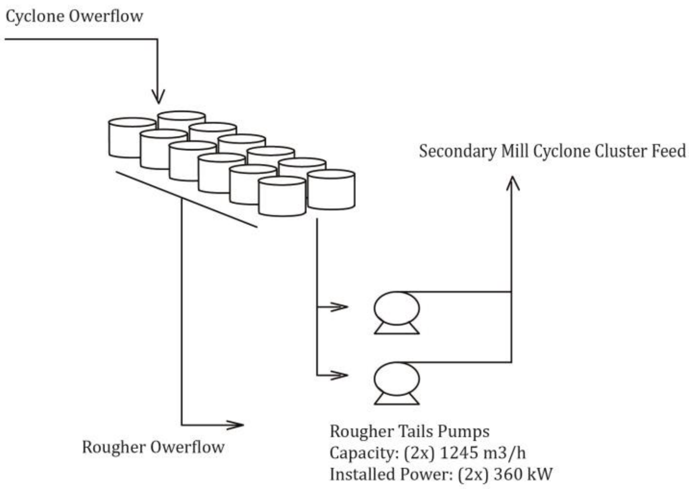

HPGR Feed Silo
Capacity: 15000 t
HPGR Feed Bin
Capacity: 1250 t
HPGR Screen Feed Bin
Capacity: 380 t
Secondary Crusher Product
406-CV-003
Capacity: 2600 tph
Installed Power: 300 kW
Length: 464 m
HPGR Screen Feed
405-CV-004
Capacity: 1563 tph
Installed Power: 200 kW
Length: 457 m
HPGR Screen Oversize
406-CV-002
Capacity: 2600 tph
Installed Power: 37 kW
Length: 88 m
HPGR Feed
406-CV-001
Capacity: 1417 tph
Installed Power: 220 kW
Length: 594 m
HPGR Bin Feed
406-CV-005
Capacity: 1000 tph
Installed Power: 30 kW
Length: 145 m
HPGR Screen Undersize
406-CV-006
Capacity: 1000 tph
Installed Power: 30 kW
Length: 145 m
HPGR Screen Undersize
406-CV-007
Capacity: 1500 tph
Installed Power: 160 kW
Length: 1046 m
Mill Silo Feed
HPGR Product to Mill Silo

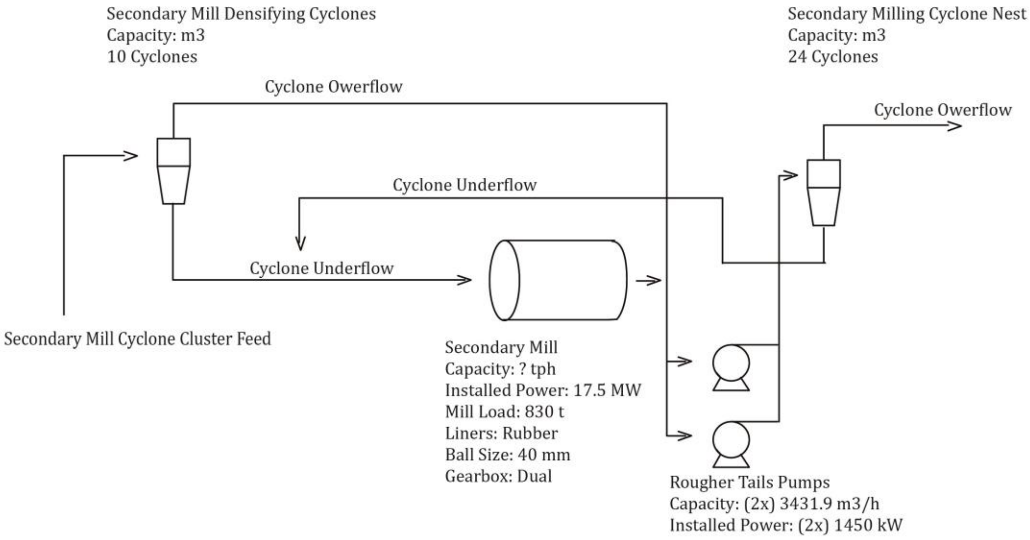

HPGR Feed Silo
Capacity: 15000 t
HPGR Feed Bin
Capacity: 1250 t
HPGR Screen Feed Bin
Capacity: 380 t
Secondary Crusher Product
HPGR Screen Belt Feeder
Capacity: (2x) 1390 tph
Installed Power: (2x) 45 kW
HPGR Feeder
Capacity: (2x) 1390 tph
Installed Power: (2x) 45 kW
HPGR Silo Belt Feeder
Capacity: (2x) 930 tph
Installed Power: (2x) 75 kW
HPGR Crusher
Capacity: 2160 tph
Installed Power: (2x) 2800 kW
HPGR Screen (x2)
Installed Power: (2x) 37 kW
Top Panel: 15 x 55 mm
Bottom Panel: 12 x 26 mm
Split Point: 8-12 mm
HPGR Product to Mill Silo


Mill Feed Silo
Capacity: 15000 t
Mill Feed Silo Feeder
Capacity: (2x) 930 tph
Installed Power: (2x) 75 kW
407-CV-001
Capacity: 930 tph
Installed Power: 55 kW
Length: 323 m
Primary Mill Feed

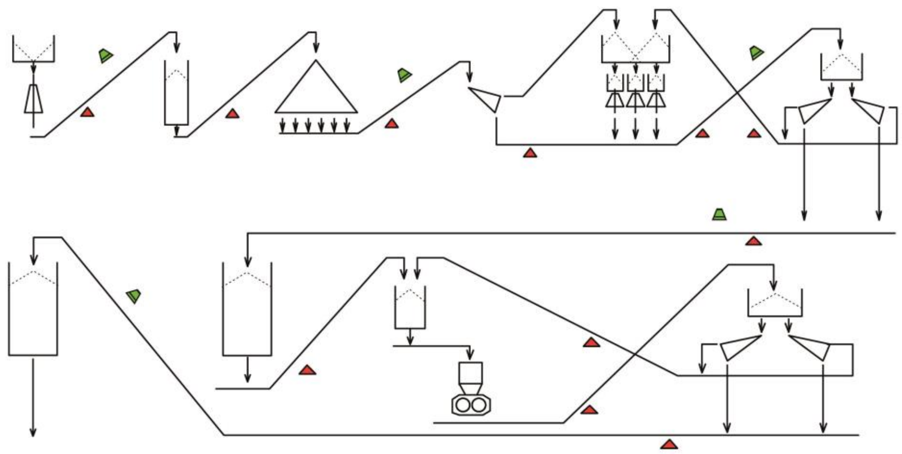

407-CV-001
Capacity: 930 tph
Installed Power: 55 kW
Length: 323 m
Primary Mill Feed
Primary Milling Cyclone Nest-1
Capacity: 660 m3
10 Cyclones
Primary Milling Cyclone Nest-2
Capacity: 660 m3
10 Cyclones
Cyclone Owerflow
Cyclone Underflow
Primary Mill
Capacity: ? tph
Installed Power: 17.5 MW
Mill Load: 830 t
Liners: Steel
Ball Size: 70 mm
Gearbox: Dual
Discharge Pumps
Capacity: (2x) 3706.8 m3/h
Installed Power: (2x) 1450 kW


407-CV-001
Capacity: 930 tph
Installed Power: 55 kW
Length: 323 m
Primary Mill Feed
Primary Milling Cyclone Nest-1
Capacity: 660 m3
10 Cyclones
Primary Milling Cyclone Nest-2
Capacity: 660 m3
10 Cyclones
Cyclone Owerflow
Cyclone Underflow
Primary Mill
Capacity: ? tph
Installed Power: 17.5 MW
Mill Load: 830 t
Liners: Steel
Ball Size: 70 mm
Gearbox: Dual
Discharge Pumps
Capacity: (2x) 3706.8 m3/h
Installed Power: (2x) 1450 kW

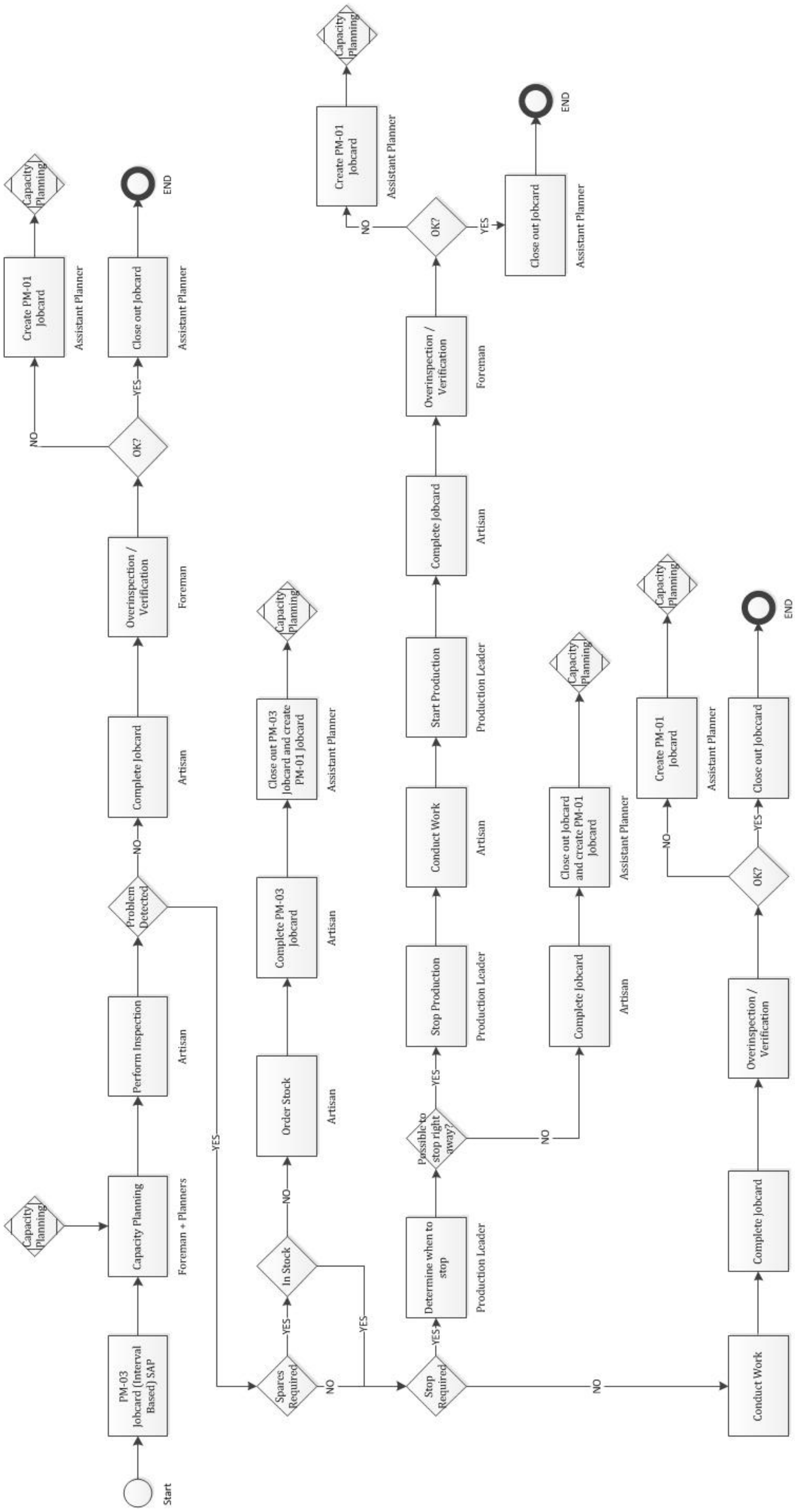

Cyclone Owerflow
Secondary Mill Cyclone Cluster Feed
Rougher Owerflow
Rougher Tails Pumps
Capacity: (2x) 1245 m3/h
Installed Power: (2x) 360 kW


Secondary Mill Densifying Cyclones
Capacity: m3
10 Cyclones
Secondary Milling Cyclone Nest
Capacity: m3
24 Cyclones
Cyclone Owerflow
Cyclone Owerflow
Cyclone Underflow
Cyclone Underflow
Secondary Mill Cyclone Cluster Feed
Secondary Mill
Capacity: ? tph
Installed Power: 17.5 MW
Mill Load: 830 t
Liners: Rubber
Ball Size: 40 mm
Gearbox: Dual
Rougher Tails Pumps
Capacity: (2x) 3431.9 m3/h
Installed Power: (2x) 1450 kW

APPENDIX III - LYNXX CAMERAS POSITIONING MAP

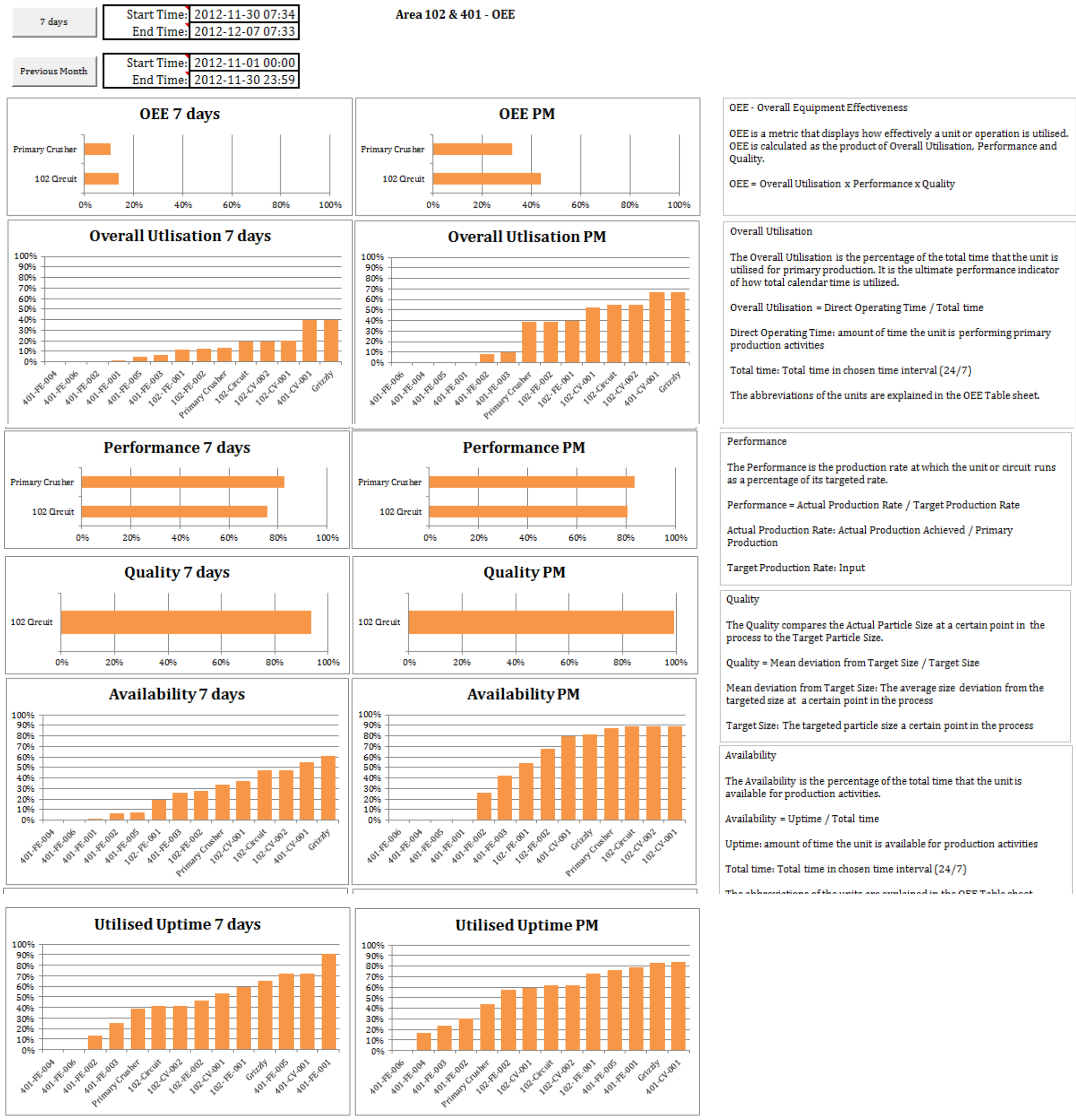


APPENDIX IV - JOB CARD INSPECTIONS AND MAINTENANCE MAP



Print Screens from the Overall Productivity Tool (OPT)
Displayed area: Area 102

APPENDIX V - OPT PRINT SCREEN



Print Screens from the Overall Productivity Tool (OPT)
Displayed area: Area 102

Area 102 - OEE Table

Start Time: End Time:	7 days	2012-11-30 07:34 2012-12-07 07:33	PM	2012-11-01 00:00 2012-11-30 23:59

	102 Circuit		Primary Crusher	
	7 days	PM	7 days	PM
Total Time (T000):	10079,00	43199,00	10079,00	43199,00
Uptime (T200)	4766	38368	3379	37646
Direct Operating Time (T300):	1980	23597	1312	16704
Availability:	47,29%	88,82%	33,53%	87,15%
Overall Utilisation:	19,64%	54,62%	13,02%	38,67%
Utilised Uptime:	41,54%	61,50%	38,83%	44,37%
Target Production Rate:	2000,00	2000,00	2800,00	2800,00
Actual Production Achieved:	49878,72	634680,20	50450,63	651855,09
Actual Production Rate:	1511,48	1613,80	2307,19	2341,43
Performance:	75,57%	80,69%	82,40%	83,62%
Quality (P80):	93,68%	99,31%		
Average Size:	135,11	144,35		
Average Deviation:	-44,89	-35,65		
Overall Equipment Effectiveness:	13,91%	43,77%	10,73%	32,33%

	102-FE001		102-FE002	
Feeders	7 days	PM	7 days	PM
Uptime (T200)	1990	23515	2768	29164
Direct Operating Time (T300):	1176	17119	1284	16711
Availability:	19,74%	54,43%	27,46%	67,51%
Overall Utilisation:	11,67%	39,63%	12,74%	38,68%
Utilised Uptime:	59,10%	72,80%	46,39%	57,30%

	102-CV001		102-CV002	
Conveyors	7 days	PM	7 days	PM
Uptime (T200)	3776	38459	4766	38368
Direct Operating Time (T3	2013	22715	1980	23597
Availability:	37,46%	89,03%	47,29%	88,82%
Overall Utilisation:	19,97%	52,58%	19,64%	54,62%
Utilised Uptime:	53,31%	59,06%	41,54%	61,50%

Area 401 - OEE Table

	Grizzly	
Classifiers	7 days	PM
Uptime (T200)	6155	35066
Direct Operating Time (T300):	4006	29057
Availability:	61,07%	81,17%
Overall Utilisation:	39,75%	67,26%
Utilised Uptime:	65,09%	82,86%

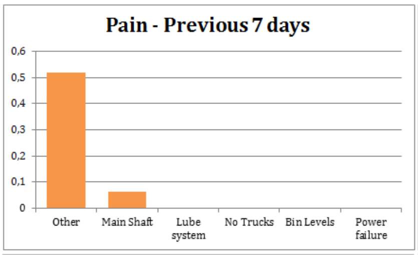
	401-CV001	
Conveyors	7 days	PM
Uptime (T200)	5561	34567
Direct Operating Time (T3	3994	29005
Availability:	55,17%	80,02%
Overall Utilisation:	39,63%	67,14%
Utilised Uptime:	71,82%	83,91%

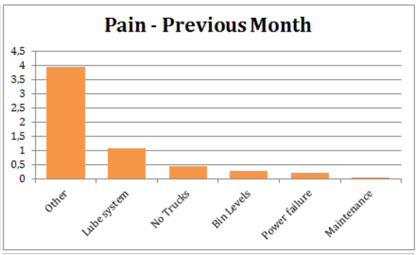
	102-FE001		102-FE002		102-FE003		102-FE004		102-FE005		102-FE006	
Feeders	7 days	PM	7 days	PM	7 days	PM	7 days	PM	7 days	PM	7 days	PM
Uptime (T200)	145	241	666	11463	2626	18216	0	18	710	229	0	0
Direct Operating Time (T300):	131	190	87	3488	667	4253	0	3	509	175	0	0
Availability:	1,44%	0,56%	6,61%	26,54%	26,05%	42,17%	0,00%	0,04%	7,04%	0,53%	0,00%	0,00%
Overall Utilisation:	1,30%	0,44%	0,86%	8,07%	6,62%	9,85%	0,00%	0,01%	5,05%	0,41%	0,00%	0,00%
Utilised Uptime:	90,34%	78,84%	13,06%	30,43%	25,40%	23,35%	0,00%	16,67%	71,69%	76,42%	0,00%	0,00%

Overall Utilisation		Rate Achieved		OEE		Availability		Quality	
From:	To:	From:	To:	From:	To:	From:	To:	From:	To:
85,00%	100,00%	85,00%	100,00%	85,00%	100,00%	85,00%	100,00%	85,00%	100,00%
50,00%	84,99%	50,00%	84,99%	50,00%	84,99%	50,00%	84,99%	50,00%	84,99%
0,00%	49,99%	0,00%	49,99%	0,00%	49,99%	0,00%	49,99%	0,00%	49,99%

Area 102 - Pain

7 days	Start	2012-11-29 10:36		Mean Time Between Failures:	563
	End	2012-12-06 10:35		Mean Time To Repair:	140
Previous Month	Start	2012-11-01 00:00		Mean Time Between Failures:	1569
	End	2012-11-30 23:59		Mean Time To Repair:	113





Area 102 - Stop Table

Start time:	2012-11-29 10:36
Stop time:	2012-12-06 10:35
Total no. of stops:	6
Total duration of stops (minutes):	839,5166667
Total duration of stops (days):	0,58

DATE		DURATION	STOP REASON	COMMENTS	DOWNTIME SUB-CATEGORY		DOWNTIME CATEGORY		SCHEDULING
STOP TIME	START-UP TIME	Duration (HH:MM:SS)	Stop reason	Manually entered comment	Downtime sub-category code	Downtime sub-category	Downtime category code	Downtime category	Scheduled/ Unscheduled
2012-11-30 04:24	2012-11-30 04:27	00:02:53	Silo Level	Feeder down	D100	Unscheduled Maintenance Event	D000	Equipment Downtime	Unscheduled
2012-12-01 04:23	2012-12-01 05:28	01:04:48	Main Shaft	shear pins broken	D100	Unscheduled Maintenance Event	D000	Equipment Downtime	Unscheduled
2012-12-01 05:28	2012-12-03 16:10	10:42:14	Conveyor	Conveyor belt worn	D100	Unscheduled Maintenance Event	D000	Equipment Downtime	Unscheduled
2012-12-03 22:37	2012-12-03 22:58	00:20:10	Other	contact discrepancy	D000	Other Downtime	D000	Equipment Downtime	Unscheduled
2012-12-03 22:58	2012-12-03 23:57	00:59:02	Other	contact discrepancy	D000	Other Downtime	D000	Equipment Downtime	Unscheduled
2012-12-03 23:58	2012-12-04 00:48	00:50:24	Other	contact discrepancy	D000	Other Downtime	D000	Equipment Downtime	Unscheduled
2012-12-04 17:19			Other	shaft coupling shear pins broken off	D000	Other Downtime	D000	Equipment Downtime	Unscheduled

APPENDIX VI - OPT MANUAL

OPT MANUAL

GUIDELINES TO THE OVERALL PRODUCTIVITY TOOL (OPT)

How to Update Calculations

1. Open the excel-file named *OPT_"areacode"*.

If a Security Warning appears, click on Options, in the bar just above the sheet (see Figure 1), and choose "Enable this content" in the dialogue box. Click OK (see Figure 2).

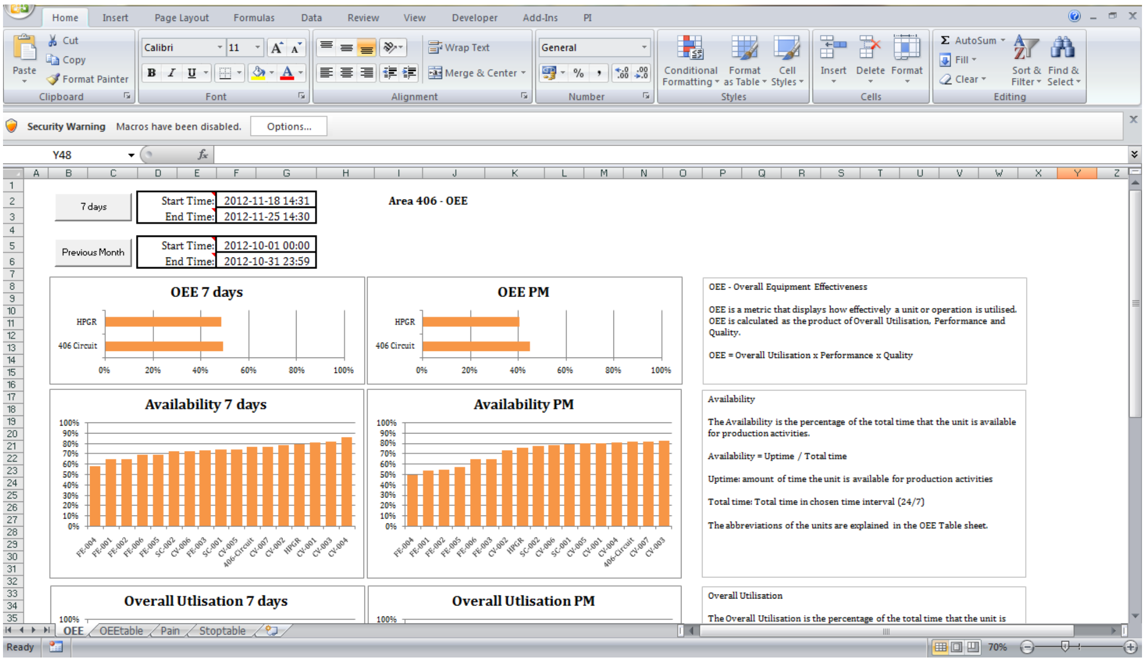


Figure 1 – Security Warning that might appear when launching OPT

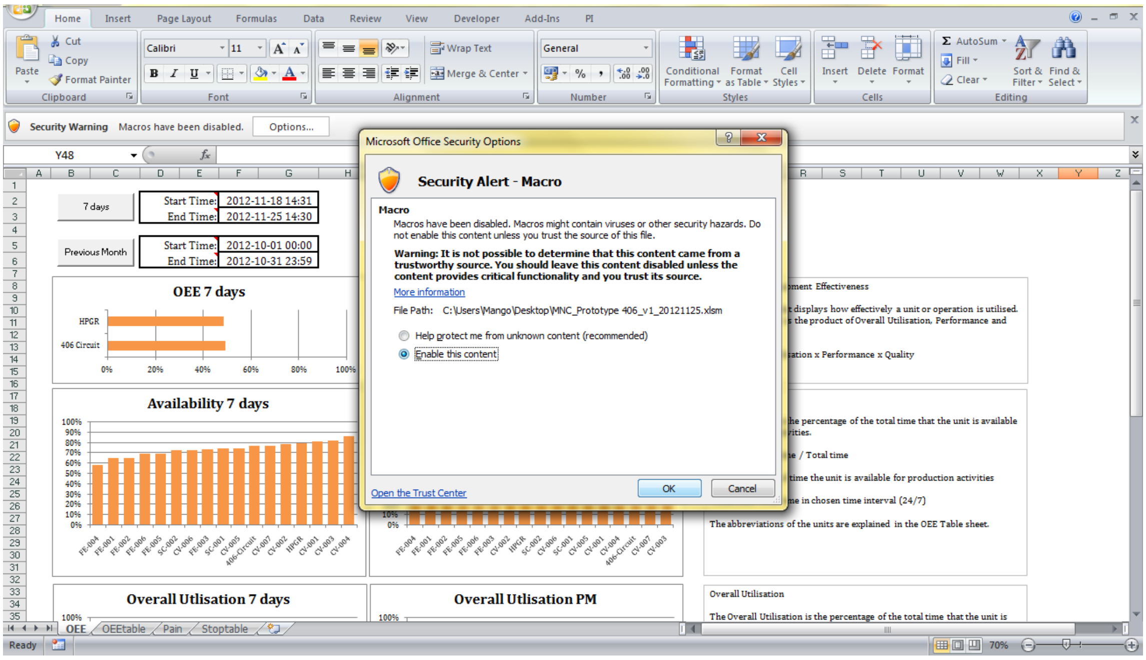


Figure 2 – How to enable macros

2. To update the OEE calculations for the previous seven days, go to the sheet "OEE", click the grey button named "7 days" and wait until a dialogue box opens and confirms the update.

3. To update the OEE calculations for the previous month, click the grey button named "Previous Month" and wait until a dialogue box opens and confirms the update.

4. To update the Pain analysis for the previous month, go to the sheet named "Pain" and click the grey button named "Previous Month" and wait until a dialogue box opens and confirms the update.
Note that the Pain analysis for the previous month has to be updated before updating the previous 7 days in order to display the stop table for the previous 7 days under OEE Table sheet.

5. To update the Pain analysis for the previous seven days, go to the sheet named "Pain" and click the grey button named "7 days" and wait until a dialogue box opens and confirms the update.

6. OPT is now updated according to the dates displayed on top of each sheet under "Start" and "End".

Note that the document shall be saved before closing down.

OEE CALCULATIONS

Two sheets in the Overall Productivity Tool (OPT) concern OEE calculations; those are named "OEE" and "OEE Table".

OEE SHEET

The OEE sheet displays charts with the OEE for the circuit and the crushing unit in the monitored area. It also displays charts with the Overall Utilisation, Performance, Quality, Availability, and Utilised Uptime for all units included in the monitored area.

The charts are sorted in ascending order to visualise what units that currently have the lowest Overall Utilisation, Availability and Utilised Uptime. The abbreviations of the units are explained in the OEE Table sheet.

To the right of the charts boxes with explanations of the charts and their metrics are provided.

At top of the sheet, the monitored time intervals are displayed. For information on how to update these and the tables to the current end time, see section How to Update Calculations.

OEE TABLE SHEET

The OEE Table sheet provides the calculations a transparency and can be used to get a more thorough understanding of the charts displayed in the OEE sheet.

The OEE Table sheet displays the components of the OEE calculations categorised by unit type (Crusher, Classifiers, Feeders, and Conveyors).

The definition of any displayed component can be viewed by hovering over the component name (see Figure 3, where the pointer is hovered over "Availability").

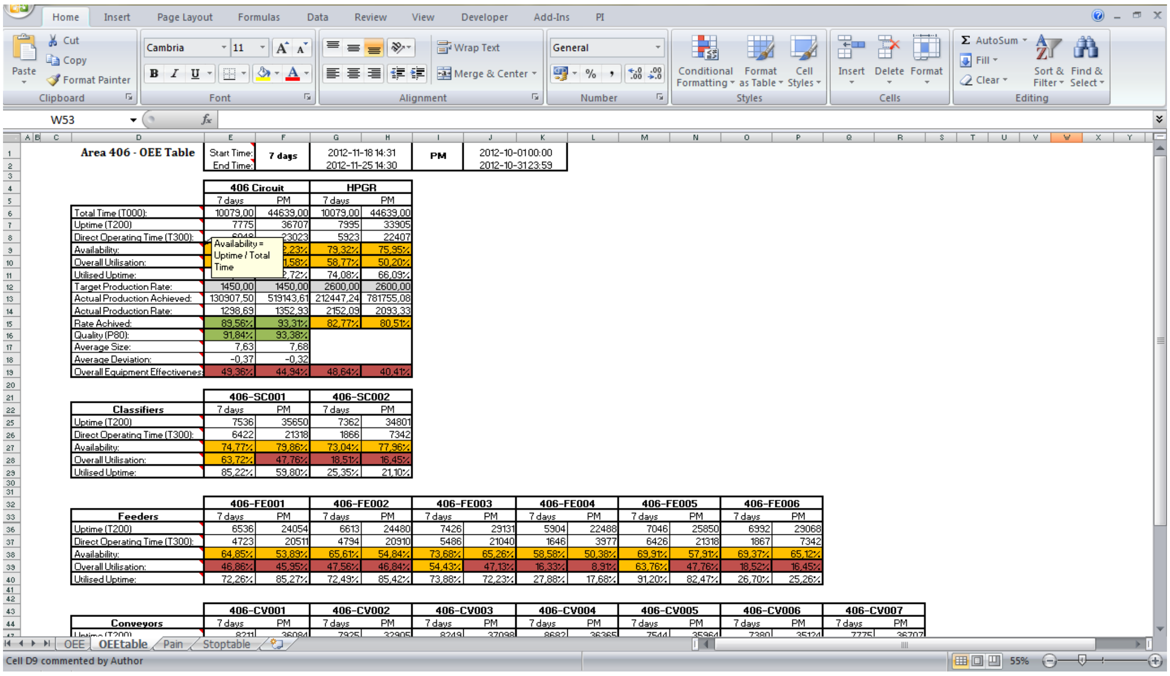


Figure 3 – Information appearing when hovering over Availability

All displayed rates (except for Utilised Uptime) have a colour code which visualises the current status. Green is for Satisfactory, yellow for Poor and red for Alarming.

Satisfactory	Poor	Alarming

The colour limits for the different units can be seen at the bottom of the sheet. The limits shall be set based on the business targets of those values and should only be changed by the administrator of OPT.
The cells with a grey background colour are target values which shall be changed if process changes resulting in target changes are performed. The target values should be changed only by the administrator of OPT.

All set targets shall be reviewed if the process has been changed in such way that the current target parameters are invalid.

Parameters to be reviewed:

- Target rates (tph)
- Target particle size
- Running definition limits for units
- Primary production limits for units

At top of the sheet, the monitored time intervals are displayed. For information on how to update these and the tables to the current end time, see section How to Update Calculations.

PAIN ANALYSIS

Two sheets in the Overall Productivity Tool (OPT)concern the Pain analysis; those are named "Pain" and "Stop Table".

PAIN SHEET

Pain is a way of visualising the combination of frequency and downtime of stops occurred in the monitored area. The Pain sheet displays charts with the top 6 Pains in the monitored area.

The charts are sorted in descending order to visualise what stop reasons that currently are causing the largest Pain. The stop reasons are labelled below each bar in the chart. The unit for the y-axis is thousand minutes, however, pain is displayed as a unitless metric.

At the top of the sheet, above the charts, Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) are displayed for the units.

At the top of the sheet, the monitored time intervals are displayed. For information on how to update these and the tables to the current end time, see section How to Update Calculations.

More detailed stop information, such as stop time, start-up time, duration of stop, comment and downtime codes, can be found in the Stop Table sheet.

STOP TABLE SHEET

The Stop Table sheet presents detailed stop information drawn from stop reporting though the PI database. The information that can be viewed is as follows:

- Stop time: The time the unit stopped
- Start-up time: The time the unit started up after the stop
- Duration: The duration of the stop
- Stop reason: The reason of the stop
- Manually entered comment: Possible manually entered comment by stand-by official
- Downtime categories
    - Downtime sub-category code
    - Downtime sub-category name
    - Downtime category code
    - Downtime category name
- Scheduled/Unscheduled: Indicates if the stop was scheduled or not

The downtime categories are used in order to facilitate the allocation of stops in alignment with Anglo American Equipment Performance Metrics Time Model.

At the top of the sheet the total numbers of stops and the total downtime in the chosen time interval are displayed. At the extreme top of the sheet, the monitored time intervals are displayed. For information on how to update these and the tables to the current end time, see section How to Update Calculations.

Definitions of Metrics

The following metrics are used in OPT and has to be understood in order to utilise OPT as effectively and correctly as possible.

OEE - Overall Equipment Effectiveness

OEE is a metric that displays how effectively a unit or operation is utilised. OEE is calculated as the product of Overall Utilisation, Performance and Quality.

OEE = Overall Utilisation x Performance x Quality

Overall Utilisation

The Overall Utilisation is the percentage of the total time that the unit is utilised for primary production. It is the ultimate performance indicator of how total calendar time is utilised.

Overall Utilisation = Direct Operating Time / Total time

Direct Operating Time (T300): Time the unit is performing primary production activities
Total time (T000): Total time in chosen time interval (24/7)

Performance

The Performance is the production rate at which the operation runs as a percentage of its targeted rate.

Performance = Actual Production Rate / Target Production Rate

Actual Production Rate = Actual Production Achieved / Primary Production

Actual Production Achieved: Actual tonnes produced during chosen time interval
Primary Production (P200): Time equipment is utilised for production.

For time definitions, see Figure 4.

Quality

The Quality looks at the P80 particle size and shows to what extent the particles size is below the targeted size. It compares the Actual Particle Size at a certain point in the process to the Target Particle Size. The Quality is defined as the mean deviation above Target Size as a percentage of the Target Size. This implies that all particles below target size results in zero in deviation. To get the Quality and not the deviation, the ratio is subtracted from 1.

$$\text{Quality} = 1 - \frac{\textit{Mean deviation from Target Size}}{\textit{Target Size}} = 1 - \frac{\sum_{i=1}^{n} \frac{\textit{Deviation from target size}}{n}}{\textit{Target Size}}$$

For time definitions, see Figure 4.

Availability

The Availability is the percentage of the total time that the unit is available for production activities.

Availability = Uptime / Total time

Uptime (T200): Time the unit is available for production activities
Total time (T000): Total time in chosen time interval (24/7)

For time definitions, see Figure 4.

UTILISED UPTIME

The Utilised Uptime is the percentage of the available time that the unit is being utilised for primary production.

Utilised Uptime = Direct Operating Time / Uptime

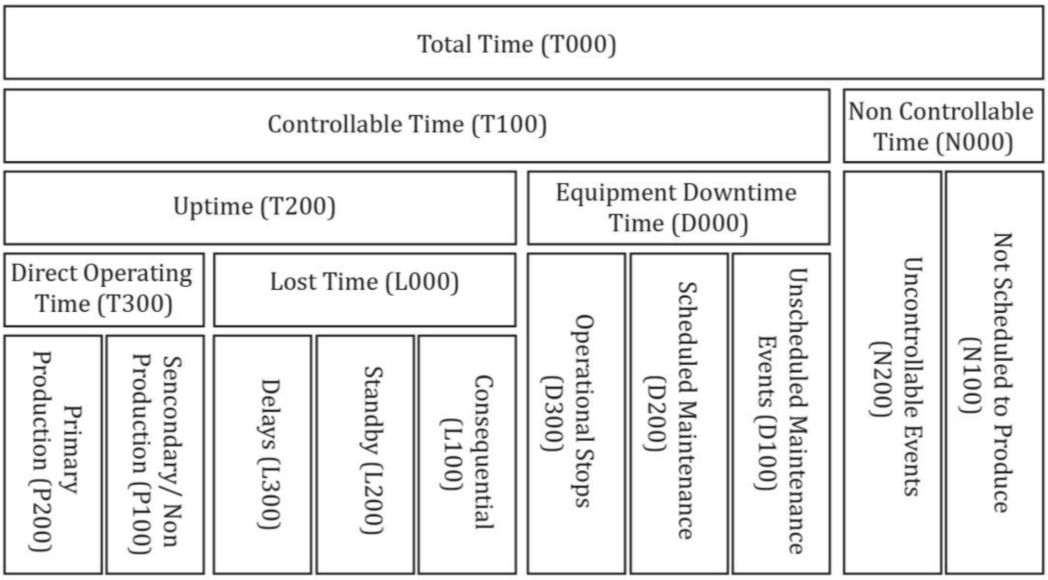


Figure 4 – Anglo American Equipment Metrics Time Model

PAIN

Pain is calculated as the product of frequency of the error and total stop time caused by the error.

Pain = Frequency of error x Total stop time caused by error

MEAN TIME BETWEEN FAILURES (MTBF)

The MTBF is the average elapsed time between failures of the unit.

MTBF = Uptime / Number of stops

Uptime (T200): Amount of time the unit is available for production activities
Number of stops ($D000_{events}$): The number of downtime events occurred during the period of time viewed

MEAN TIME TO REPAIR (MTTR)

The MTTR is the average time required to repair the failed unit.

MTTR = Equipment Downtime Time / Number of stops

Equipment Downtime Time (D000): Downtime that renders the equipment inoperable
Number of stops ($D000_{events}$): The number of downtime events occurred during the period of time viewed

EXAMPLES OF HOW TO INTERPRET VALUES

The outcome of the Overall Productivity Tool can be analysed and interpreted in several different ways. This section will explain some fundamentals when analysing the metrics. These examples might not always be valid but can provide user with an idea of what information that can be drawn from OPT.

5 WHYS

A general recommendation when analysing the outcome of OPT is to use the method 5 WHYs. The goal is to find the root cause of the problem. When the root-cause is found, a conclusion of what to do should be drawn and an action to resolve the problem should be taken. If the encountered problem is complex, a Ishikawa diagram can be used to find multiple root causes (see Figure 5).

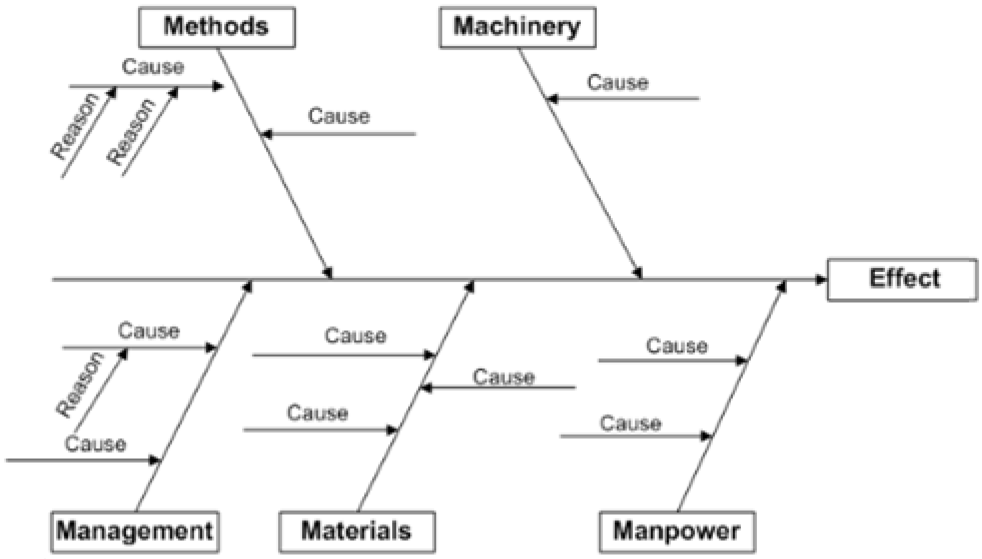


Figure 5 – Ishikawa (or fishbone) diagram to help find multiple root causes

OEE

OEE is not just a number; it can be up to four numbers – the OEE, Overall Utilisation, Performance and Quality. It is important to look into all the factors when analysing an OEE number. If an OEE number found in the OEE sheet is found to be of interest, it can be viewed in more detail in the OEE Table sheet. There, all components of the OEE can be seen and analysed individually.

LOW OEE	A low OEE indicates a non-effectively utilised unit or circuit. To help increase the OEE, the factors included has to be known. The included factors can be seen in OEE Table sheet. The components of a factor can be seen when hovering over it.
HIGH OEE	A high OEE indicates an effectively utilised unit or circuit. Even though a unit or circuit has a high OEE, it should not be neglected. A well performing unit or circuit can provide information about how to run a unit or circuit effectively. The user should learn from this and apply it on other units and circuits.
OVERALL UTILISATION	The Overall Utilisation shows to what extend the unit has been utilised for production. It is the ultimate performance indicator of how total calendar time is utilized.
LOW OVERALL UTILISATION	A low Overall Utilisation indicates a small proportion of Direct Operating Time, which is when the unit is performing production activities. If the unit has not been utilised, it could be due to internal issues or factors outside of its boundaries, such as low feed. The Overall Utilisation can be increased by extending the Direct Operating Time, i.e. the time when the unit is actually producing.
HIGH OVERALL UTILISATION	A high Overall Utilisation indicates a large Direct Operating Time, which is when the unit is performing production activities. A unit with high Overall Utilisation can provide useful information on how this can be achieved. The user should learn from this and apply it on other units.
PERFORMANCE	The Performance shows the production rate at which the unit or circuit runs as a percentage of its targeted rate. This means that the targeted rate has a large influence on the achieved Performance; therefore, it is highly important that the Target rate is carefully determined. Otherwise, the Performance measure will be misleading.
LOW PERFORMANCE	A low Performance indicates a Production Rate far below the targeted rate during the primary production time. This can be due to either a very long production time or low production achieved. To increase the Performance, a higher achieved production has to be reached during the production time or the same amount of production has to be reached in shorter time.
HIGH PERFORMANCE	A high Performance indicates that the production rate is close to the targeted Production Rate. A unit or circuit with high Performance can provide useful information on how this can be achieved. The user should learn from this and apply it on other units and circuits.
PERFORMANCE >100%	The Performance can exceed 100%. This will occur when the Production Rate is greater than the Target Rate. This indicates that the target rate has to be reviewed. If process changes have been made in such way that

the current target parameters are invalid, the Target Rate shall be adjusted accordingly.

QUALITY

The Quality looks at the P80 particle size and shows to what extent the particles size is below the targeted size. It looks at the mean particle size deviation above the targeted size. This implies that all particles below target size results in zero in deviation, hence 100% in Quality.

LOW QUALITY

A low quality indicates that the mean particle size is far above the Target Size. The actual particle size and mean deviation are displayed in the sheet "OEE Table". If the Quality is low, the downstream process might be affected and it should be beneficial to look at the performance of the downstream units.

HIGH QUALITY

A high Quality indicates a mean particle size below the Target Size. If all particle sizes are below the targeted size, the Quality will be 100%. The actual particle size and mean deviation are displayed in the sheet "OEE Table".

AVAILABILITY

The Availability shows to what extend the unit has been available for production. It does not have to be used during that time; however, it has to be available. Availability has a strong connection to Overall Utilisation. Those two metrics are complementary since they present the unit running time in two different aspects. The Availability is in most cases a larger number since it is including a broader span of time, i.e. all the time the unit has been switched on, whereas the Overall Utilisation only includes the time the unit has been performing production.

LOW AVAILABILITY

A low Availability indicates a large proportion of non-running time. The Availability can be increased by extending the unit Uptime, which implies reducing the unit downtime. For the crushing units, the downtimes can be seen in the Stop Table sheet.

HIGH AVAILABILITY

A high Availability indicates a large proportion of running time. This implies that the downtime and non-controllable time both are low. A unit with high Availability can provide useful information on how this can be achieved. The user should learn from this and apply it on other units.

UTILISED UPTIME

To show the ratio between Availability and Utilised Uptime, a rate called Utilised Uptime is displayed in OPT. The Utilised Uptime is the proportion of the Available time that has been utilised for production.

LOW UTILISED UPTIME

A low Utilised Uptime indicates a low utilisation of the time the unit actually has been available for production. This shows a possibility to increase the production of the unit by only increasing the utilised time, without increasing the available time of the unit or reducing the unit stop time. In fact, if the availability increases and the production time is constant, the Utilised Uptime will decrease.

High Utilised Uptime

A high Utilised Uptime indicates a high utilisation of the time the unit has been available for production. An Utilised Uptime of 100% indicates that all available time has been utilised for production. This means that both the available time and the utilised time have to be increased in order to increase production. A unit with high Utilised Uptime can provide useful information on how this can be achieved. The user should learn from this and apply it on other units.

PAIN

The Pain charts show the top 6 highest Pains for the crushing unit.

High Pain

A high Pain of a failure indicates one of the following:

- High frequency of failure
- Large downtime caused by failure
- Both high frequency and large downtime caused by failure

High Pains points out what areas cause most problems and should be investigated and resolved.

MTBF

Mean Time Between Failures (MTBF) shows the average elapsed time between failures of the unit.

Low MTBF

A low MTBF indicates that the unit fails frequently. The aim is to maximise the MTBF. Actions should be taken to investigate how to solve the problem.

High MTBF

A high MTBF indicates that the unit does not fail frequently. A unit with high MTBF can provide useful information on how this can be achieved. The user should learn from this and apply it on other units.

MTTR

Mean Time To Repair (MTTR) shows the average time required to repair the failed unit.

High MTTR

A high MTTR indicates that the downtime per failure is long. The aim is to minimise the MTTR. Actions should be taken to investigate how to solve the problem.

Low MTTR

A low MTTR indicates that the downtime per failure is short. A unit with low MTTR can provide useful information on how this can be achieved. The user should learn from this and apply it on other units.

APPENDIX VII - OPT MEETING PROCEDURE

OPT Meeting Procedures — Updated 2012-12-05

1. Meeting Preparations

To Be Completed by Meeting Holder Prior to Meeting

1. Update OPT (procedure described in OPT Manual)
2. Review the Action List for OPT

2.

	Input	Action	Output
Follow Ups	Action list Information of issued tasks	Go through action list from previous meeting If action completed: - Fill in Completion date - Responsible person shall inform about results of action - Meeting participants shall draw conclusions of action and its result - Conclusions which result in a need for further actions shall be documented as new actions in Action list OR If action outstanding: - Why? - Need to re-fine action in order to accomplish it? - If yes, re-fine action and add to Action list. - Else, update due date and make sure action is performed.	If action completed: Action list updated with: - Completion date - Result - Conclusion Possible new action based on conclusions from completed action If action outstanding: Action list updated with: Refined action OR New due date

1(2)

OPT Meeting Procedures — Updated 2012-12-05

3.

	Input	Action	Output
Running OPT	Recently updated OPT	Go through OEE and Pain sheets Perform analysis Use 5 WHYs to search for root causes View OPT Manual for: - Explanations of OEE sheets - Explanations of Pain sheets - Definitions of metrics - Help with analysing the outcome **Note** that findings which result in a need for further actions shall be documented as new posts in Action list	New actions in Action list

4. Fill in Action List

1. Open the file "Action List for OPT"
2. Fill in the table except for Completion Date, Result and Conclusions, which shall be filled upon action completion

Note that the responsibility roles "Accountable" and "Responsible" have to be filled in for all actions.

Figure 1 – The OPT Method

2(2)

APPENDIX VIII - OPT ACTION LIST

Action List for OPT

Action list to be filled when using the Overall Productivity Tool (OPT)

Number of outstanding tasks	3

	ACTION	RESPONSIBILITY ROLES				DATE		OUTCOME	
Completed?	Action	Responsible	Accountable	Consulted	Informed	Due date	Completion date	Result	Conclusions
Yes	Check "Maintenance" on CR002	Natalie	Natalie	Dane	-	2012-12-01	2012-11-30	"Maintenance" referred to liner change	Create a new more specified failure reason
No	Create failure reason (see above)	Albert	Dane	-	Ellie, Natalie	2012-12-10			
Yes	Check possible measure error on CV002	John	Philip	-	Dane	2012-12-01	2012-12-02	Sensor damaged, sensor changed	Point check sensors on conveyors
No	Improve rutines for maintenance	Phillemon	Natalie	Dane, John		2012-12-30			
No	Develop condition monitoring for Grizzly clogging	Dane	Natalie	John, Philip		2013-01-14			
Yes	Check spigot on cyclones	Felix	Dane	Herman		2012-11-25	2012-11-23	Different spigot size on installed cylones	Change to similar sizes