

# **Predictive Maintenance as a Means to Improve the Availability of Centrifugal Slurry Pump at Ergo City Deep Plant**

**Aroon Martinus, Jan Harm C Pretorius and Arie Wessels**

Post Graduate School of Engineering Management, University of Johannesburg, Johannesburg,  
South Africa

aroonm@uj.ac.za, jhpretorius@uj.ac.za, [ariewessels@gmail.com](mailto:ariewessels@gmail.com)

## **Abstract**

Centrifugal slurry pumps are used in many applications such as in the mining, chemical and in the industrial plants. Ergo City Deep Plant uses centrifugal slurry pumps to pump slurry from its pumping station to Elsburg pumping station over a distance of about 50 km. Due to unplanned breakdowns, the pumps are not operating at peak efficiency point, and as a result the plant does not meet its monthly production target. Ergo City Deep Plant used reactive (breakdown) maintenance, which had escalated the maintenance operating costs year on year. In this study, predictive maintenance through condition monitoring techniques was used to improve the availability of centrifugal slurry pump. This research proved that predictive maintenance is a better maintenance method for centrifugal slurry pumps than reactive maintenance, because the pumps availability increased by 49 %, the downtime and maintenance costs have also been reduced simultaneously by 58%. Furthermore, also production losses have been reduced, and therefore boosted the profit margin of the organization.

## **Keywords**

Centrifugal slurry pumps, Downtime, Maintenance cost, Predictive maintenance and Condition monitoring.

## **1. Introduction**

In recent years, there has been an increasing concentration in maintenance within the business sector. This is a result of escalating pressure upon mining operations to meet customer and corporate demands, as well as improving equipment availability and performance (Baglee and Knowles 2010). Therefore, maintenance with its various activities, resources, measurement and management, has become critical to mining operations (Simoes et. al 2011). In this respect, maintenance have to play an important role in helping organizations to reach their goals of productivity, profitability and competitiveness and making sure that their equipment operates effectively and efficiently (Baglee and Knowles 2010).

Maintenance, as describe by (Gustavsson et al. 2014), is the function of retaining an item or, restoring it to its original state or, acceptable standard for use 'or to meet its functional standard'. Maintenance is generally accepted as a time consuming and costly activity that may render equipment unavailable if not effectively practiced (Narayan 2012). (de-Smidt-Destombes et al. 2004) stated that, proper plant maintenance could significantly reduce overall operating costs, and boost plant productivity and organization's profit.

Maintenance strategy is a long- term plan, covering all aspects of maintenance management, which sets the direction for maintenance management, and contains firm action plans for achieving a desired future state for the maintenance function (Dunn 2009). It is therefore, important for an organization to adopt to the 'correct' maintenance strategy to enhance its performance.

Figure 1 depicts the different types of maintenance strategies before and after detecting the failure.

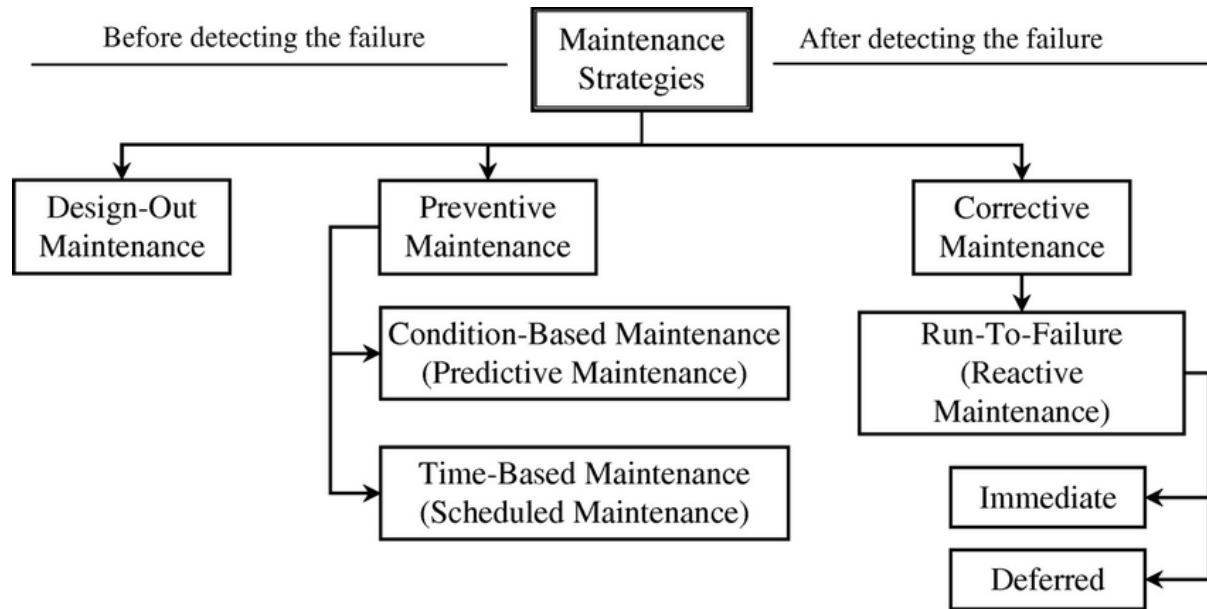


Figure 1. : Maintenance Strategies (Rastegan and Salonen, 2013)

Corrective (reactive) maintenance is the oldest form of maintenance. It operates on the basis that the equipment is repaired only when it is failed or it is about to fail. This maintenance approach is unscheduled and often entails repair actions. It requires no maintenance management and is the most expensive approach as it results in increased equipment downtime, reduced production and high resource costs (Blanchard 2012). Run-to-failure is the most common form of corrective maintenance.

Preventive maintenance (PM) can be seen as a proactive approach as maintenance tasks are performed before failure occurs thus reducing the chance of failure. This maintenance approach is executed at predetermined intervals. Some of the factors that it is based on are, machine hours and cycle times. This approach entails searching for conditions that cause equipment deterioration that will result in equipment failure. It is important to note that PM does not completely eliminate equipment downtime but it does reduce it (Govender, 2015).

Examples of Preventive maintenance approaches are, conditioned – based monitoring, this type of maintenance entails performance and parameter monitoring. This monitoring maybe scheduled when required or completed on pre-determined intervals, redundancy which entails having a back – up system built into the main system to increase plant availability, and lastly scheduled maintenance where maintenance is executed on an established time schedule.

Predictive Maintenance is based on the regular monitoring of actual mechanical condition, operating efficiency, and other indicators of the in-service equipment through inspection and condition monitoring techniques (Zahorulko and Volodymyr 2014). During inspection, maintenance personnel determine the condition of the equipment or component by using instruments through benchmarking. The most suitable and less costly condition monitoring tools available for rotating machinery are visual inspection, vibration analysis, lubrication and oil analysis, and acoustic (noise level) analysis.

The four areas that should be incorporated in a pump maintenance program are, pump performance monitoring and pump system analysis, vibration monitoring, acoustic (noise level) analysis and visual inspection (Kernan 2010).The

main objective of this research is to employ Predictive Maintenance as a means to improve the availability of centrifugal slurry pump at Ergo City Deep Plant.

### **1.1 Background to the research problem**

(Hydraulic Institute and Europump 2011) proved that maintenance costs contribute about 30 – 45 % of the total life cycle cost of large industrial pumps. These vary widely depending on the complexity of the process and the duty of the pump. In larger companies, reducing maintenance expenditure by R7 million contributes as much to profits as increasing sales by R21 million (Wireman 2009). (Blanchard 2012) explains that the key measure of system performance is plant availability, which in turn is a function of reliability and maintainability. Equipment reliability means effective maintenance. Maintenance costs in the mining industries are commonly between 30 – 50 % of mine site total operating costs (Krellis and Singleton 1998).

(Parhboo 2014) states that South Africa spends R578 million on imported pumps, whereas R564 million is spend on locally manufactured pumps. The typical life cycle costs for a pump are: 5% capital; 5-25% maintenance (depending on type of product being pumped); 70-90% on energy consumption. Based on these finding, it is implied that South Africa spends R500 million to R2.5 billion on maintenance annually (Museka 2015).

To reduce maintenance costs, maintenance activities need to be reduced. This can only be achieved by extending the life of equipment components and avoiding in - service failures. (Krellis and Singleton 1998) explains that from a total cost perspective, the key drivers of maintenance costs are the Mean time between Failures (MTBF) or equipment reliability and the Mean time to Repair (MTTR). By extending these key factors, costs will be reduced and plant availability will be improved.

### **1.2 Importance of the study**

According to (Daley and Kim 2010) Achieved and Operational Availability are not always the same. If you operate, maintain and inspect a device, you will be able to harvest all the inherent. If there are gaps in your operating, maintenance or inspection practices, you harvest a portion of the availability.

The research aims to improve the pump availability by using operating parameters data to determine whether the availability of the overall system is being kept at a maximum. When running at best efficiency the pump is supposed to output a flow rate and head according to the system curve of the pump.

A deviation from the system curve on parameters being monitored during predictive maintenance would indicate that there is a decrease in reliability in the system components (motor, pistons, and valves) which results in the overall unreliability and unreliability of the pump.

The purpose of the study is to research how predictive maintenance can increase the availability of the pump, investigate the impact on log elements of maintenance by increasing the MTB and decreasing the MTTR, and lastly to reduce maintenance and operational costs for a centrifugal slurry pump

The research is going to describe the condition monitoring technique which can be used to gather ongoing data for pump performance. The data gathered during condition monitoring will be used to indicate the schedule for the next maintenance task to ensure the system is always available.

### **1.3 Factors that influence pump availability**

(Blanchard 2012) defines operational availability as the instantaneous probability that a system or component will be available to perform its intended function when called upon to do so at any point in time. (Barringer 2006) states further that, availability deals with the duration of uptime for operations and is a measure of how often the system is alive and well.

Availability is defined as  $\text{Uptime} / (\text{Uptime} + \text{Downtime})$  (Barringer 2006). The availability of a pump on site is influenced by the physical condition of the pump and the operating environment (Stapelberg 2006). In the case of slurry pumps the characteristics of the slurry have a significant impact on the pump performance and availability

(Khalil et al. 2013). The variations in process variables are often the root-cause of the observed mechanical failures of the pump (Museka 2015).

$$\text{Availability} = \text{MTBF} / (\text{MTBF} + \text{MTTR}) \quad (1)$$

$$\text{MTBF} = 1 / \text{failure rate} \quad (2)$$

#### **1.4 The importance of gland service on the availability of slurry pumps**

Horizontal slurry pumps operate in harsh environments and pump abrasive materials that form part of the by-product associated with the mineral extraction process of the mine operation. According to (Metso 2013), ‘the shaft seal is the most important function in any slurry pump’.

(Ridgway et al. 2009) describe gland sealing as ‘a process whereby pumps separate the pumped fluid (slurry) from the external environment particularly in duties where the process pressure and temperature are high and the solids content in the liquid exceeds 5 % and the fluid is corrosive’.

Gland water according to (Ridgway et al. 2009) is ‘a hydrostatic lubricant that lubricates the packing/shaft sleeve interface, it flushes any solids from the seal into the pump and it rejects thermal energy develop by friction between packing fibres and the shaft sleeve’, therefore gland service is a vital component to sustain the life of the gland seal. Once the stuffing box fails, the slurry pump seizes and the whole tailings plant grinds to a halt.

According to one of the leading slurry manufacturing companies Weir Minerals, ‘the most critical requirement for achieving satisfactorily gland life is the supply of gland flush water at the correct pressure’ (Weir Minerals 2009).

Hench gland service also entails adequate supply of ‘clean’ water into the stuffing box of a slurry pump at a specific pressure needed to overcome the back pressure from the slurry pump. The back pressure of the slurry pump causes the liquid medium of the slurry pump to surge out of the stuffing box if the correct gland service has not been applied. Once the slurry pump ‘slimes’ i.e. the stuffing box gets full of slurry, the slurry pump wears excessively and fails. Common conditions that contribute to this are: gland seal water pressure is lower than the pump impeller boss pressure; gland water flow is too low and packing tends to harden with age as the boundary lubricant is squeezed or melted from the packing and the voids between packing fibres close under compression. Thus, the lateral pressure coefficient approaches zero (Ridgway et al. 2009).

When the slurry pump fails, the entire train may come to a halt, as the slurry train is unable to make the desired pressure needed to pump the slurry to the next pump station or treatment plant. When the slurry train is not operational, the entire process of the mine comes to halt which results in large production losses.

The gland service pump is generally a multi- stage pump, which is a high pressure pump that supplies the desired flow rate into the stuffing box of the slurry pump at a pressure that is 50 to 100 kPa higher than the slurry pump ‘s operating pressure. Different slurry pump manufacturers recommend different gland service operating pressures. For example, Ergo City Deep Plant requires that the gland service pressure must be at least 150 kPa higher than the delivery pressure. The common conclusion is the gland seal water must operate at a higher pressure than the operating pressure of the slurry pump being supplied with gland seal water.

#### **1.5 Problem Statement**

Ergo City Deep Plant is currently performing reactive maintenance on the slurry pumps. Basically the pumps are working until breakdowns occur before any maintenance is performed. The maintenance costs and downtime are increasing year by year (DRDGOLD FY 2016).

However, the plant data shows that the pumps are delivering flow rates between 1050-1150 m<sup>3</sup>/hr which is below the minimum required flow rate of 1370 m<sup>3</sup>/hr. According to the Original Equipment Manufacturer (OEM) manual these pumps should deliver maximum flow rates of 1857 m<sup>3</sup>/hr. Predictive maintenance through condition monitoring will be used to increase the pumps flow rate, with the view to meet the required flow rate.

## **2. Methodology**

The researcher administered a structured questionnaire to collect data from Ergo City Deep Plant Maintenance personnel. Open-ended interviews were also conducted with the Maintenance personnel. The Maintenance personnel are the Mechanical and Electrical fitters, Maintenance Foreman. The questionnaires and interviews were conducted with the Control Room Operators, Production Manager, Procurement Manager and the Sales Manager of Weir Envirotech® (Pty) Ltd. The population size was twelve participants with a sample size of five pumps.

### **2.1 Study metrics**

This research study used quantitative research methods to meet the research objectives. The parameters on which data was collected are pump run times; failure history of the pumps; Mean Time between Failure (MTBF) and classification of failures.

### **2.2 Data collection**

Data was collected through questionnaires and open-ended questions interviews, which were conducted by the researcher in 2017. This was done on-site during working hours of the respective participants. The core purpose of this exercise was to learn which maintenance method is being used in the plant, and to identify the main causes of pump failures. The second set of data was collected by performing condition monitoring on the five primary pumps. The condition monitoring technique, mainly through visual inspection of the pumps gland services, measured the flow rate output of each pump.

### **2.3. Data analysis and interpretation**

The data gathered was modelled using an Excel Spreadsheet by means of a control chart to advise on the state of the pumps and the corrective action that needs to be employed on them.

## **3. Results and Discussion**

### **3.1. Results and Findings of the Questionnaires**

From the questionnaires, it was observed that no predictive maintenance is done at Ergo City Deep Plant; the pumps are run-to-failure. As a result, the plant experiences high down times and maintenance costs, subsequently not meeting its production targets. Furthermore, it was also observed that most of the artisans do not understand the term 'predictive maintenance' and the purpose thereof.

### **3.2 Results and Findings from the Field data**

The data gathered in this study is from the period when the pumps had already been in operation for at least three years. The pumps chosen are five pumps which are connected in series and were installed at approximately the same time. The historical data of the total failures on each pump and the classification of failures are going to be stated for the periods from 2014 to 2017. Predictive maintenance was implemented in June 2017.

Failures are categorized as follows:

- A- Mechanical failures - shaft sleeve, gland packing, bearings etc.
- B- Electrical failures – motor drive
- C- Physical failures – 'choking' of suction pipeline, wear and tear on V-belt etc.

Table 1. Summary of total downtime cost before predictive maintenance

Category	Downtime cost, ZAR		
	2014	2015	2016
A	300 000	420 000	480 000
B	400 000	400 000	400 000
C	12 000	48 000	84 000
Total	712 000	868 000	964 000

Table 2. Summary of total downtime before predictive maintenance

Category	Downtime, hrs		
	2014	2015	2016
A	40	56	64
B	9	9	9
C	4.5	18	31.5
Total	53.5	83	104.5

Table 1 and 2 illustrate that the downtime costs and downtime increase year by year respectively. This could be explained by the fact that the pumps remain on breakdown for hours due to shortages of critical spare parts, especially for the mechanical components. The filing system that's been used currently proves to be ineffective as no records of stock levels are documented or recorded. This will definitely have an impact on the pump availability and subsequently on production targets.

For the plant to meet its monthly production target, management needs to introduce a much more effective procurement management system. Low plant availability and overtime costs definitely affect the organization's operational efficiency (Ahmad and Benson 2007).

### 3.3 Predictive Maintenance Implementation

Table 3 illustrates the costs and downtime after predictive maintenance was implemented in June 2017.

Table 3. Summary of total downtime costs and downtime after predictive maintenance

Category	Downtime costs, ZAR	Downtime, hrs
	2017	
A	120 000	16
B	200 000	4.5
C	36 000	13.5
Total	356 000	34

From table 3 one can observe that the costs and downtime have both been reduced by 58% after the implementation of predictive maintenance. It was also observed that the plant experienced less pump failures in 2017 (see Annexure 1 for additional information).

### 3.4 Flowrate output curves of all five pumps

An online monitoring system can be incorporated to monitor the pump's flow rate output, which provides an indication of the pump's condition (Heinr 2006). Ergo City Deep Plant uses a Supervisory Control and Data Acquisition (SCADA) system to monitor the flow rate output of the pumps. Another technique that is also employed at Ergo City Deep is to monitor the power consumption of the pump and bench mark the reading with the design specifications of the pump. If the pump draws too much current, it is an indication that there is a poor pulley tension or misalignment. The pump is then stopped and corrective action is taken. This technique is not illustrated in this paper. An online flow rate monitoring system provides condition monitoring information for predictive maintenance, but additional techniques are required to detect all possible failures that may occur. Figure 2 illustrates the flowrate output trends from the SCADA system:

Green trend line - Transfer flow rate of all five pumps  
Red trend line - Slurry transfer density  
Purple trend line - Level of the slurry tank  
Blue trend line - Gland service water pressure

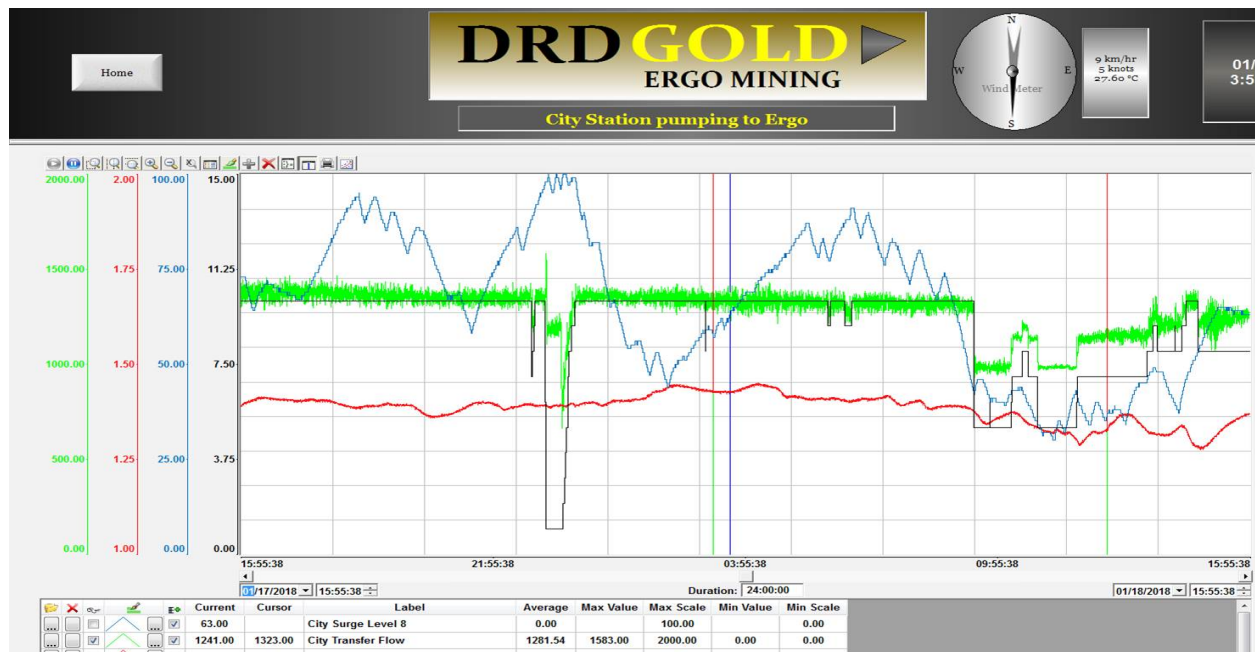


Figure 2. Flowrate output trends from SCADA system

It is clear from Figure 2 that predictive maintenance through condition monitoring was applied, where the gland service water pressure was higher than the delivery pressure of the pump. No pump failures occur and the transfer flow rate was within acceptable transfer levels of between 1480 m<sup>3</sup>/hr and 1500 m<sup>3</sup>, and also within the daily target mass flow transfer of 20 000 tons/day. Furthermore, the slurry density was also within the plant's specifications of between 1.40 kg/m<sup>3</sup> and 1.45 kg/m<sup>3</sup>. The slurry density has a direct impact on the performance and availability of the pump. If the slurry density is not within specifications, the rate of wear will increase and the motor could be overloaded (Chandel et al. 2011, Khalil et al. 2013).

### 3.5. Failure rates of each pump

Table 4 illustrates the failure rates of each pump annually.

Table 4. Failure rates of each pump annually

Pump	2014	2015	2016	2017
1	1.00	0.50	0.50	0.33
2	1.00	0.50	1.00	0.25
3	0.50	0.25	1.00	0.33
4	0.50	0.33	1.00	0.33
5	0.50	0.50	1.00	0.25

It is evident from table 4 that the failure rates decreased after predictive maintenance was implemented. A decrease in failure rate means a MTBF growth, which means the pumps become more reliable (Barringer 2006). Predictive Maintenance therefore improves the availability of centrifugal pumps by 49%. The availability was calculated using equation (1) and (2). Some information like the frequency of pump failures and MTTR were not reported as it has been treated as highly confidential information in accordance to Ergo City Deep Plants policy.

### 3.6 Future Work

This work was streamlined to the challenges that aroused at Ergo City Deep Plant with the main objective to improve the availability of centrifugal slurry pumps. Due to fact that gland service is vital to the life span of a slurry pump, the following suggestions emanated from this research: the need for Effective Management Model in a gland service system for mining operations, and the importance of clean gland service water on the life service of the gland seal packing.

Lastly, predictive maintenance can be used as an effective management strategy to improve plant availability and to reduce production losses in mine tailings plants.

## 4. Conclusion

From the research field data, one can conclude that Predictive Maintenance has improved the availability of a centrifugal slurry pump by 49%. The pumps failure rate falls within the base failure rate of 0.1 - 0.35 as per the Pump Manufacturer's recommendations (Museka 2015). Since predictive maintenance was performed, the MTBF has increased as the failure rates were reduced, downtime has been reduced, hence the increase in pump's availability.

This research proved that predictive maintenance is a better maintenance method for centrifugal slurry pumps than reactive maintenance, because the pumps availability increased by 49%, the downtime and maintenance costs have also been reduced simultaneously by 58%. Furthermore, also production losses have been reduced, and therefore boosted the profit margin of the organization.

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## **Biographies**

**Aroon Martinus** is currently the Head of Technical Staff within the School of Mining, Metallurgy and Chemical Engineering at the University of Johannesburg. Mr. Martinus holds a Bachelor of Science degree with Chemical Engineering subjects from Stellenbosch University, South Africa, a Postgraduate qualification in Business Management and Economics and a Masters of Philosophy in Engineering Management both from University of Johannesburg. He also holds Postgraduate qualifications in Labour Law relations within the context of the South African Labour Law Act and Project Management both from University of South Africa. Mr. Martinus has completed investigative research projects with BMW (South Africa) and also worked as a Process Engineer in the Metallurgy and Mineral Processing Industries. His research interests include Reliability Engineering, Modeling and Simulation and Plant Operations Management.

**Jan-Harm Pretorius** obtained his BSc Hons (Electrotechnics) (1980), MIng (1982) and DIng (1997) degrees in Electrical and Electronic Engineering at the Rand Afrikaans University and an MSc (Pulse Power and Laser Physics) at the University of St Andrews in Scotland (1989), the latter *cum laude*.

He worked at the South African Atomic Energy Corporation (AEC) as a Senior Consulting Engineer for fifteen years. He also worked as the Technology Manager at the Satellite Applications Centre (SAC) of the Council for Scientific and Industrial Research (CSIR). He is currently a Professor and Head of School: Postgraduate School of Engineering Management in the Faculty of Engineering and the Built Environment. He has co-authored 200 research papers and supervised over 35 PhD and 220 Master's students in Electrical Engineering and Engineering Management. He is a registered professional engineer, professional Measurement and Verification (M&V) practitioner, senior member of the Institute of Electrical and Electronic Engineering (IEEE), fellow of the South African Institute of Electrical Engineers (SAIEE) and a fellow of the South African Academy of Engineering.

**Arie Wessels** worked as a System Engineer in the South African Defense Industry until retirement. Dr. Wessels holds a Bachelor of Science in Electrical Engineering (1968) from University of Johannesburg formerly known as Rand Afrikaans University, a Masters in Engineering Management (*cum laude*) (1997) and a PhD in Engineering Management (2013) from Pretoria University, South Africa. He has taught courses in Engineering Management and he also supervising and mentoring Post Graduate Students. He has extensive knowledge in Systems Engineering with specific reference to Complex Systems Design.

## Supplementary Information:

### Annexure 1: Maintenance cost and downtime before Predictive Maintenance

Table A.1. Cost of Repairs and Downtime

Failure Classification	Cost of failure in Rands	Downtime hours	Year 1	Year 2	Year 3
A	60 000	8	5	7	8
B	200 000	4.5	2	2	2
C	12 000	4.5	1	4	7

Calculations of the Downtime:

A = Time for isolation + Logistic for spare part + Installation + Commissioning  
 $= 2 + 2 + 3 + 1$   
 $= 8$  hours

B = Time for isolation + Logistic for spare part + Installation + Commissioning  
 $= 1.5 + 1 + 1.5 + 0.5$   
 $= 4.5$  hours

C = Dismantling + Re-work of piping + Commissioning  
 $= 2 + 2 + 0.5$   
 $= 4.5$  hours

Calculation of the Total Downtime Cost due to Failures:

The total downtime cost is the cost of failure per category of failure x frequency of failures

For example in Year 1 the total costs due to downtime:

Cost of failure A + Cost of failure B + Cost of failure C  
 $= (60\,000 \times 5) + (200\,000 \times 2) + (12\,000 \times 1)$   
 $= \text{R } 712\,000$

Table A. 2. Downtime costs and downtime

Failure Classification	Downtime Costs in Rands			Downtime in hours		
	Year1	Year 2	Year 3	Year 1	Year 2	Year 3
A	300 000	420 000	480 000	40	56	64
B	400 000	400 000	400 000	9	9	9
C	12 000	48 000	84 000	4.5	18	31.5
Total	712 000	868 000	964 000	53.5	83	104.5

Calculation of the Total Downtime due to Failures:

For example, the total downtime for Year 1 is calculated as follows:

Downtime of failure A + Downtime of failure B + Downtime of failure C  
 $= (8 \times 5) + (4.5 \times 2) = (4.5 \times 1)$   
 $= 53.5$  hours

Maintenance costs and downtime after Predictive Maintenance

Table A. 3. Cost of Repairs and Downtime

Failure Classification	Frequency of failures	Cost of failures in Rands	Downtime of failures in hours	Total cost of failures in Rands	Total Downtime in hours
A	2	60 000	8	120 000	16
B	1	200 000	4.5	200 000	4.5
C	3	12 000	4.5	36 000	13.5
Total	6			356 000	34

Decrease in downtime costs  $= (R\ 712\ 000 + R\ 868\ 000 + R\ 964\ 000)/3 = R\ 848\ 000$   
 $= (R\ 848\ 000 - R\ 356\ 000)/(R\ 848\ 000) \times 100\ \% = 58\ \%$

Decrease in downtime  $= (53.5 + 83 + 104.5)/3 = 80.3$   
 $= (80.3 - 34)/80.3 \times 100\ \% = 58\ \%$