Application of Reliability Engineering in a Chemical Plant to Improve Productivity

Vuyo Terrence Hashe and Makgomo Thelma Mamatlepa

Abstract This paper is based on reliability case study conducted in a chemical company (Company X) based in Germiston South Africa. The work conducted focused on the causes of production loss due to poor equipment reliability that lead to downtimes. In the chemical, the production team generates works orders through an autonomous maintenance exercise which is aimed at identifying potential equipment defaults before they cause a breakdown. The works orders are categorized under corrective maintenance schedule. There are also time based preventative maintenance works orders that are created on System Application Program (SAP) for critical equipment and their components. More often, the response time from the maintenance team is slower and leads to subsequent breakdowns and production stoppages. The financial documents of the chemical plant showed that on average the plant spends $31,000 per month on maintenance cost. Projections indicate that this could easily amount to more than $376,000 per annum provided that there is no mid-term to long-term intervention to address equipment failures. The main objective of this study is to investigate the causes of reoccurring system failures using the reliability concepts and provide a solution specific to Company X which could be expanded to other companies and industries. This study followed both a qualitative and descriptive case study research approach. Data collection was carried out by attending to equipment breakdowns, observations during the normal daily operations, during production times, studying the historical available maintenance and technical relevant data, staff interviews, company internal information regarding the financial spending for the year of study. Finding indicated that the plant maintenance programmes were inadequate and needed to be revitalised by the introduction and implementation of reliability centred maintenance (RCM) process. The RCM process was suggested to address the issue of identifying key priority equipment responsible for major downtimes and analysing the failure modes so to suggest corrective actions before failure occurs.

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K. Panuwatwanich and C. Ko (eds.), *The 10th International Conference on Engineering, Project, and Production Management*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-15-1910-9_45

Keywords Downtime · Maintainability · Reliability

1 Background

As early as the 1940s, atmospheric pollution became a problem in most cities in the United States. This was as a result of mass production of cars powered by the internal combustion of engines, which were generating large quantities of man-made urban pollution. This forced the US government in the 1970s to revise the Clean Air Amendment Act which required emissions from car exhausts to be reduced by 90%. The amendment of this act prompted the need for specified technologies to eliminate pollution from cars.

In the early 1970s, Company X successfully developed and demonstrated the positive benefits of platinum containing catalysts to clean up car exhaust emissions. Today, Company X is a leading global supplier of catalytic converters, with manufacturing plants in several regions across the globe as depicted on the geographical illustration in Fig. 1.

In order for Company X to adapt to new and changing markets, the plant has setup stringent key performance indicators (KPIs). Amongst these KPIs, the most important one is to achieve a lead-time target of 6 days in the chemical salts section

Fig. 1 Global presence of Company X

of the plant. This target forces the production team to increase performance for increased significant value for the business. Although KPIs have been revised, the plant's performance in comparison to the revised KPI is still far off from the target. This mainly due to consistent equipment failures and breakdowns in the plant.

2 Methodology and Data Collection

A case study approach is used where the researcher is interested in acquiring insight and understanding of why a certain instance happened the way it did (Noor 2008). Biggam (2008) highlighted that case studies observe characteristics of an individual unit of interest. For this research, this method helped to understand the contributing factors to downtime in the chemical plant, how equipment failure affects plant performance and also availability of critical equipment in the plant.

Tomo (2010) asserts that critical components such as valves, gauges, agitators etc. in a production plant can affect individual operations and the entire process negatively if not reliable. The downtimes associated with such failures can results in losses of production value and escalate the maintenance costs if not addressed timely. Figure 2 presents the average batch lead times per month that were achieved. This data shows an inconsistent performance failing to meet the lead-time target of six days.

Based on the historical performance, equipment and machinery breakdowns play a significant role on failure of the plant to achieve budgeted lead-time target due to uncontrolled failures during the process. Production plant maintenance can be costly if low reliable equipment is in operation (Tomo 2010; Barringer 2004). Unexpected failures occur without a warning and production is constantly interrupted. Production

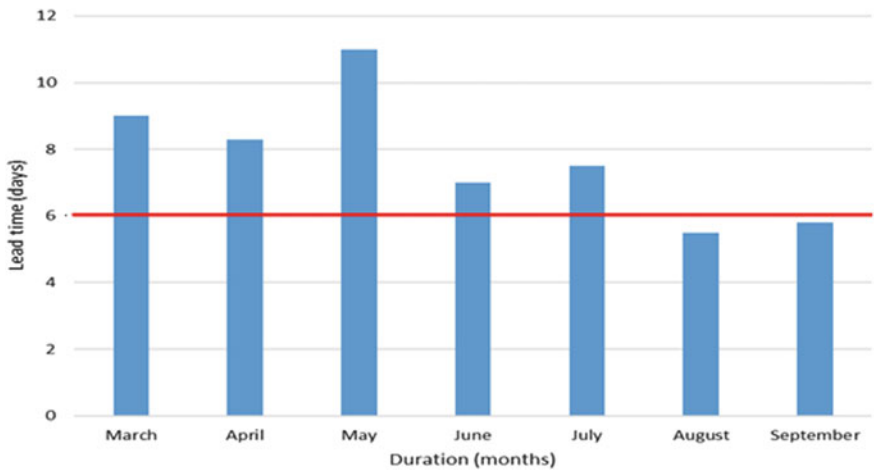

Fig. 2 Average lead-time for platinum batches

interruptions lead to longer processing times, this comes with financial ramifications due to the contractual obligations. Moreover, equipment used in the chemical plant is specialized and external contractors (Original equipment manufacturers, OEMs) service some components. The repair or replacement process during breakdowns comes at a costly price. The financial documents of the chemical plant show that on average the plant spends $34,000 per month on maintenance cost and projections show that this could easily amount to more than $408,000 per annum provided that there is no mid-term to long-term intervention to address equipment failures.

The chemical plant has various processes and in one of the processes called the Salts Process, the production team generates works orders through an autonomous maintenance exercise which is aimed at identifying potential equipment defaults before they cause a breakdown. The works orders are categorized under corrective maintenance schedule. There are also time based preventative maintenance works orders that are created on SAP (System Application Program) for critical equipment and their components. More often, the response time from the maintenance team is slower and leads to subsequent breakdowns and production stoppages. The number of work orders varied over month end due to shortage of spares, staff shortage and more urgent equipment breakdowns amongst other factors. Figure 3 shows sluggish completion of works order from the first 3 month with an improvement during the last four months. However, in August and September an increase is noted. Ultimately, this has a negative effect on equipment availability because these preventative and corrective maintenance work orders are intended to proactively maintain equipment before they fail and improve availability of critical equipment.

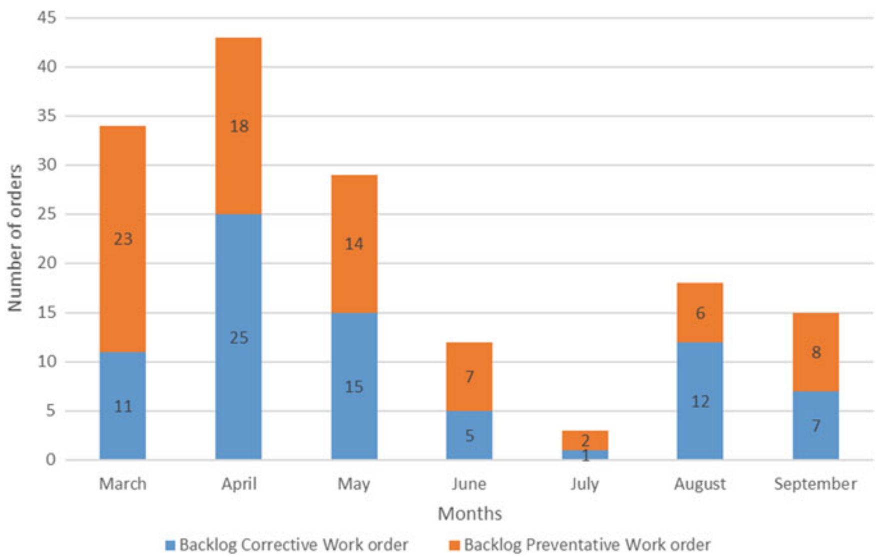

Fig. 3 Preventative and corrective maintenance orders backlog

Cowing et al. (2004) concluded that product reliability is no longer regarded a luxury product attribute but has become a selling point that is crucial for business to acquire new customers and keep existing customers. Tomo (2010) highlighted the importance of doing more with less by pointing out that the practice of cutting down on maintenance may results in catastrophic failures that come at high repair costs. In his explanation, to better define or identify these failures, one has to look at the repair cost and the consequent loss in production.

Data was collected from daily plant activities whereby every process delay was recorded with total duration of the delay or downtime. Production personnel are responsible to record this information as required by the process works instructions. The platinum process is the longest in the chemical plant that makes it more prone to delays due to the numbers of complex stages and equipment that the product passes through.

The collected data was consolidated to determine the factors causing the plant downtimes. The collected data was recorded in a spreadsheet which indicated the each process standard time built-in, therefore every excessive time was quantified and cause of delay was recorded. A reliability engineering analysis method, Pareto was used to graphically present the data and identify problematic areas affecting downtime in the chemical plant. Pareto is known as the 80/20 rule, whereby the focus according to the distribution will be on key elements that offer the largest financial gain. In essence, 10–20% of items on the Pareto distribution will account for 70–80% of the finical impact (Barringer and Monroe 1996).

2.1 Chemical Plant Layout

The chemical plant is presented in Fig. 4 where the process starts with 3 reactors in connected in parallel. R1 (V1001), R2 (V1002) and R3 (V2002) are all process initiating reactors, arranged as a parallel system and availability of each of the reactors is independent of the other. Failure in one of the reactors does not affect the whole system but flexibility of the plant. R4 (V2005), R5 (PTMF), R6 (V2010) and R7 (V2013) are intermediate processing reactors in series, whereby each one of them

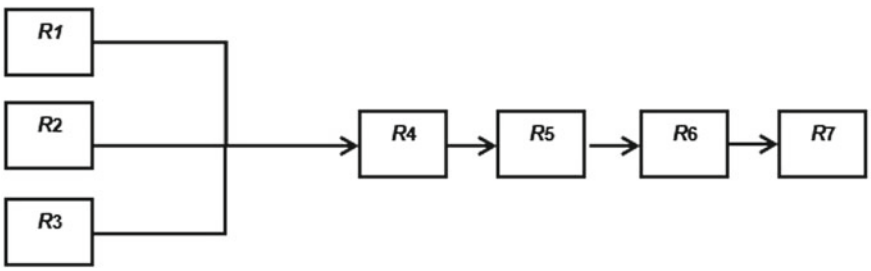

Fig. 4 Plant layout—critical section

performs a different function. From the reliability point of view, the process may be considered as serial system from R4 (V2005) up to R7 (V2013), meaning that failure of any machine or sub-system causes the entire system to halt.

According to Blanchard and Fabrycky (1998) reliability and availability of a system presented in Fig. 4 is given by Eqs. 1 and 2 respectively.

$$Reliability = R1 + R2 + R3 - (R1)(R2)(R3) \tag{1}$$

$$\text{Availability} = \text{Mean time before failure}/(\text{Mean time before failure} + \text{Mean time to repair}) \tag{2}$$

Mean time before failure (MTBF) and mean time to repair (MTTR) are given by Eqs. 3 and 4 respectively.

$$MTBF = \frac{1}{\lambda} \quad where\, \lambda\, is\, the\, rate\, of\, failure \tag{3}$$

$$\text{MTTR} = \text{Total maintenance time/number of repairs} \tag{4}$$

$$Downtimw = minutes\ per\ year * (1 - availability)\, minutes/year \tag{5}$$

2.2 Plant Downtime

Figure 5 presents the breakdown of downtimes from March to September, where every month equipment downtime is consistently higher followed by process downtime. The month of May was an exception, with most of the downtime attributed to production planning. It can be observed from Fig. 5 that equipment downtime is consistently higher followed by process downtime. A similar study by Tomo (2010)

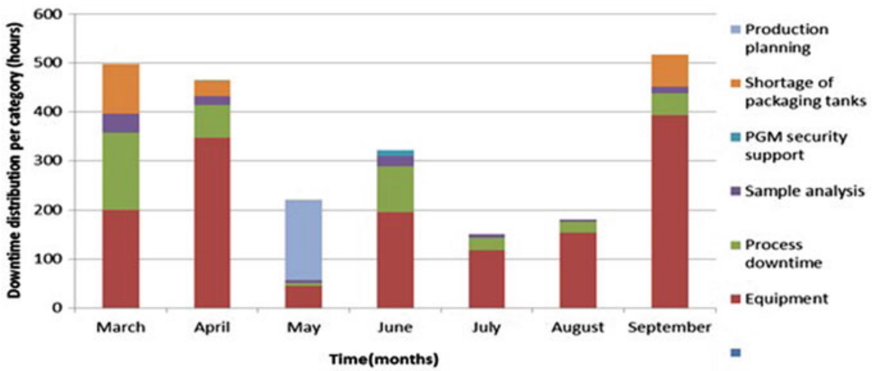

Fig. 5 Overall Downtime per Month

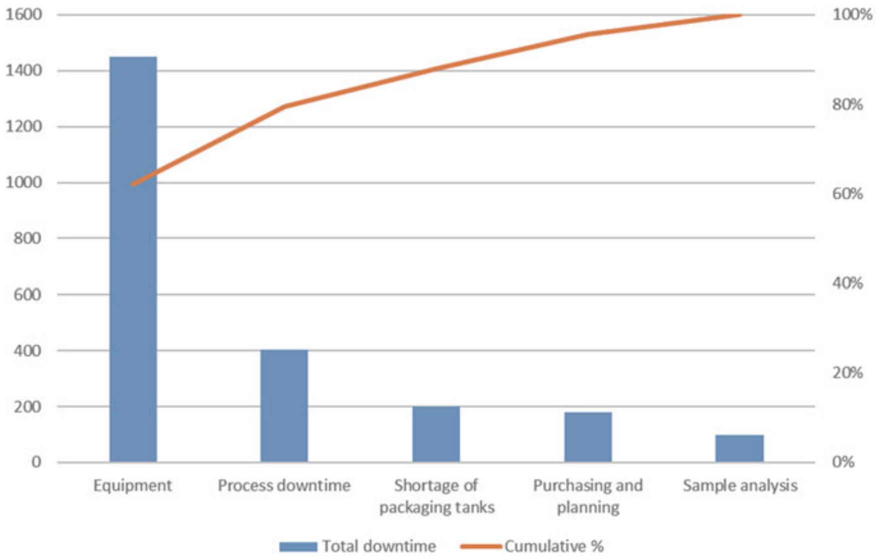

Fig. 6 Pareto Analysis of Downtime Categories

at Sasol Chemical plant concluded that not only equipment failures caused the major downtimes but factors such as raw material shortage, utility outage, planned shutdown, process control and product quality also contributed to production downtime or loss.

According to Bauer et al. (2009) downtime as a reliability index that is mainly associated with unavailability of a system and is given by Eq. 5. Equation 1 was used after identifying the key components in the chemical plant and the results are presented by Pareto Analysis chart in Fig. 6. From the Pareto analysis, it is evident that majority of the downtime that requires immediate attention is caused by equipment breakdowns and process downtime. The application of Pareto analysis is an effective tool to use to identify factors cause failure and downtime in a plant environment (Okorie and Osarenmwinda 2013).

3 Data Analysis

The total equipment downtime was further broken down into individual unit to identify sections of the plant that are problematic. Figure 7 presents the critical equipment that contributed to downtime in the plant during the period of March to September. Two reactors, V2005 (R4) and V2002 (R3) connected series as presented in Fig. 3, Pt membrane filter leads the chart followed by mechanical seals and utilities, in order of severity.

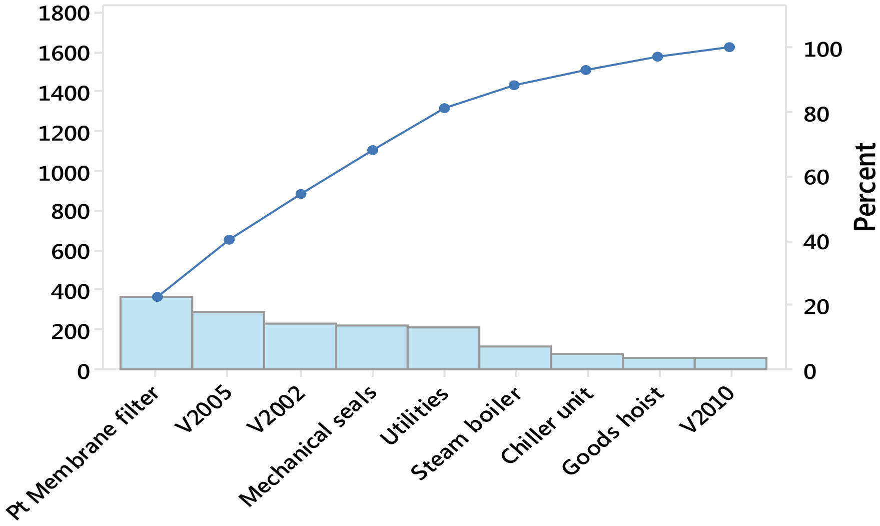

Fig. 7 Total downtime per equipment

Mushtaev et al. (2004) cautioned that most industrial plants are complex and more often the provision of reliability for such plants is based traditional methods from reliability theory that were initially designed for routine plants. This leads to inaccuracy of results from the industrial plant and this renders the results unreliable because one cannot make a well-informed decision from that data. Figure 8 shows the frequency of failures experienced at the critical equipment. The reactors R3 and R4 experienced the most downtimes. Barringer and colleagues (Barringer 2000, 2004, 2006) suggests that mean time before failure (MTBF) need to be determined once the critical equipment have been identified. MTBF is defined is a measure of reliability of repairable items and therefore helps in planning maintenance activities, should breakdowns occur.

Figure 7 shows that 78 equipment failures happened during the period of study with MTBF calculated at 0.027 failures per hour and mean time before failure (MTBF) at 37.04 h calculated from Eqs. 3 and 4. This could be interpreted to say it takes at least one and half day (37.04 h) for a critical equipment to fail in the chemical plant of study. Critical equipment availability was calculated and found to average at about 94.63%. Interviews conducted at the plant indicate that the company does not have set standards regarding the target critical equipment availability.

From the literature, the study showed that choosing the right maintenance method is critical. By comparison, preventative maintenance focuses on preventing failures or incidents by promptly replacing or repairing equipment during routine shutdown or scheduled inspections before they fail and create unnecessary stoppages. This study has revealed that the Chemical plant was using a more reactive approach (corrective maintenance) to maintain equipment in the plant. Due to this approach, the maintenance team struggled to complete all corrective maintenance tasks and

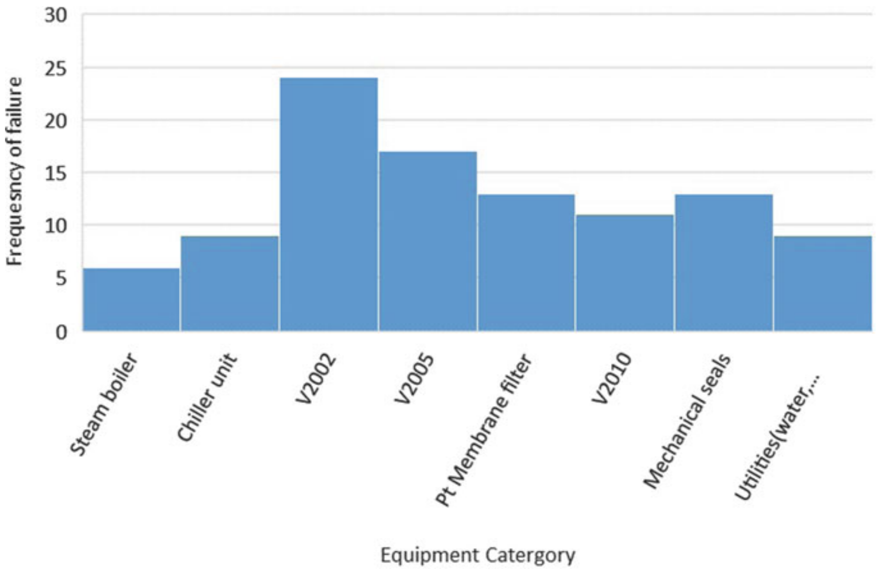

Fig. 8 Frequency of failure per critical equipment

this puts the plant at risk due to sudden failures experienced. Reliability centered maintenance should be adopted in the Chemical plant. Researchers like (Nabhan 2010; Vatn 2007) view reliability centered maintenance as the logical way used to determine what equipment need to be maintained on preventative maintenance basis as opposed to run-to-failure basis. It allows for the performance data of critical equipment to BE collected and analysed to identify specific failure modes. The information is crucial for use in the formulation of preventative maintenance.

Currently the organization does not analyze data for equipment availability in the Chemical plant; this was corroborated by the plant maintenance foreman. This simply means that there is no defined target for availability of equipment in the plant. Figure 9 shows the critical equipment availability for the duration of this study. It can be noted that availability fluctuates between 92.67 and 96.59%. The plant experienced its lowest availability for critical equipment in July, with the rest of the months being above 93%.

The results further reveal that reliability data for the plant is never analyzed to come up with better maintenance philosophies that can be used to improve reliability of the plant and reduce frequent failures in the plant. Although data analyzed shows 10% availability of critical equipment, Mashtaev et al. (2004) argued that certain facets of reliability theory should be revised for application in industrial plants; such as failure.

It can be noted from Fig. 10 that equipment is a major contributor to plant downtime, contributing 62% of plant unavailability. Process related downtime category constitutes 18%, shortage of packaging tanks is third at 8%, and inefficiency of the production plan contributes 7% and sample analysis coming fifth at 5%.

Fig. 9 Critical equipment availability

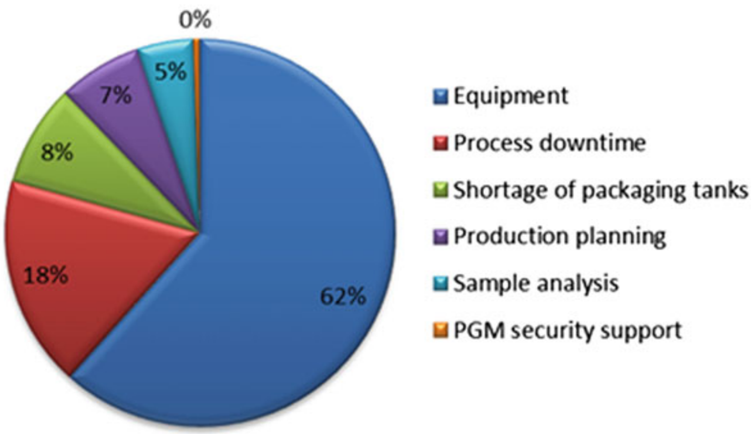

Fig. 10 Total equipment loss

4 Conclusions

The study revealed that major contributing factor to production downtime is equipment failures. Throughout the duration of this study, it was noted that the plant was not available to its maximum capacity. The study showed that critical equipment failure contributed to 10% of the plant unavailability. It further identified equipment that needed the most urgent attention to improve availability and reliability of the plant. These results show the need to focus to focus on reliability of equipment in the Chemical plant, followed by process downtime. According to the Pareto rule, focusing on two will boost the plant performance as they are the main contributors to downtime.

Critical equipment data was collected for the duration of this study and analyzed. From the empirical data, it was noted that availability of critical equipment fluctuated between 92.67 and 96.59%. There was a point where the plant experienced lowest availability of 93%. This shows inefficiency of maintenance practices in the plant. From the data analysis, it was clear that vessel V2002, V2005 and Pt membrane filter were the ones experiencing more failures, implying that they have a shorter mean time to failure (MTTF).

The results show a serious need for RCM to monitor and improve equipment availability in the plant. According to Maoto (2012) in order to have a systematic manner of controlling reliability of a system, the theory of RCM needs to be applied. When RCM is applied, failures that can lead to higher life cycle cost will be managed by proper equipment maintenance strategies. These strategies must be natured by continuously monitoring execution and reviewing their effectiveness every now and again.

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