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Engineering Maintenance Planning and Scheduling Review: A Case Study of Brick Manufacturing Company

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Abstract

Engineered systems are prevalent to failures when they are in operation. Therefore, maintaining their reliability is critical to ensure they continue operating safely and reliably for their entire lifespan. However, continuously planning and scheduling their reliability maintenance functions is necessary to improve their operation, availability, and overall reliability. Through a case study, the research study evaluates maintenance strategic approaches on a critical asset in a brick manufacturing process to improve the reliability of the asset for quality production. Based on historic failure analysis, optimized maintenance plans and schedules are derived and implemented on the asset to reduce or eliminate unplanned work.

Keywords
Maintenance Planning and Scheduling, Maintenance Strategies, System Reliability, Proactive Maintenance, Reactive Maintenance.

Introduction
System or asset reliability is very important in ensuring the expected performance and production or service quality. Engineered systems are bound to fail if they are not maintained accordingly during their operation. It is often heard from other departments within the operation that system or asset maintenance work is solely meant for engineering personnel, and this has put so much pressure on limited human resources that engineering departments mostly operate with. In other instances, planning and scheduling of reliability maintenance functions are left to junior or low-skilled personnel in the organization or even outsourced to another business outside the organization as its often considered administrative than strategic. Maintenance planning and scheduling include the choice of maintenance strategies, whether time-based, condition-based, or a combination thereof.

Maintenance of engineered systems for reliability is about continuous planning, scheduling, organizing, and controlling of all the maintenance work so that repairs, replacement, or modification of technical systems are accomplished, and that they perform their intended functions for a specified period (Visser 1997; Duffuaa and Raouf 2015). The main objective of this function is to maximize the safety, availability, and reliability of a physical asset, and to achieve that, planning and scheduling maintenance work has to be performed to ensure overall system reliability. Nel (2006) thinks that maintenance planning is key to a maintenance management framework and further suggests that maintenance planning functions must be both strategic and tactical. Strategically, maintenance planning must focus on the vision, mission, and key objectives of the maintenance system or department, whilst tactical is more concerned with short-term objectives and leads to the development of a maintenance plan for each item of the tactical system and detailed planning for each maintenance task (Nel 2006).

Sometimes, the function of identifying a critical asset for maintenance purposes through risk analysis in an operation is often overlooked. Although this function does not only assist with the maintenance of the asset, it can also assist with the identification of risk areas such as poor or deficient quality production or service that the business needs to put critical measures on, to avoid any mishap. In engineering maintenance, planning, and scheduling must include the alignment of maintenance tasks with respective maintenance strategies, and such alignment must include aspects such as the choice or selection of maintenance approach, that is proactive or reactive.

1.1 Objective

The study discusses a case for the optimization of maintenance plans and schedules, using a hybrid maintenance strategy, which includes both time-based and condition-based approaches. The case aimed to reduce unplanned work or breakdowns on a critical asset that resulted in poor quality production of bricks. Based on historic failure analysis of recorded breakdowns on a critical asset in a brick manufacturing company, the study discusses optimized maintenance plans, schedules, and strategies that were adopted for improving availability, operation, reliability of an asset, and the quality of product produced by an asset.

1. Literature

Maintenance management on engineered systems can be achieved through various maintenance strategies (Campbell and Reyes-Picknell 2006; Duffuaa and Raouf, 2015). However, such strategies are mainly classified into two categories, which are proactive and reactive maintenance approaches. The proactive maintenance strategic approach comprises planned activities related to preventive maintenance, predictive maintenance, time-based maintenance, condition-monitoring-based maintenance, reliability/risk-centered maintenance, turnaround maintenance, or total productive maintenance. Whilst reactive maintenance is unplanned work, and involves ad-hoc repairs, modifications, or replacements.

In a nutshell, proactive maintenance strategies can be classified into two categories, i.e. condition-based maintenance (CBM) and time-based maintenance (TBM) (Ahmad and Kamaruddin 2012). De Jonge et al. (2017) reviewed studies that compare CBM and TBM, considering practical factors of condition-based versus time-based maintenance and concluded that all factors affect the benefit of CBM over TBM significantly, and advised that companies need to assess the relative importance considering different factors in practice and thereafter judge whether a relative benefit exists between the two approaches. In this research study, the two strategic categories were combined to optimize maintenance work on an asset.

2.1 Proactive Maintenance

Also known as planned or preventative maintenance. This type of system maintenance is a foresight process that ensures that all necessary resources and time are made available to accomplish maintenance tasks. It is an old and established maintenance approach that was discovered after 1940 (Murthy et al. 2002), and according to Murthy et al (2002), only corrective maintenance was performed before 1940 by a specialized maintenance workforce that was called after equipment failure so that they can return the system to operation. Duffuaa and Raouf (2015) further allude that proactive maintenance was identified through predictive, condition-based, and reliability-centered maintenance and an integrated effort that seek to convert most of the maintenance work into scheduled maintenance. It is through pre-planned activities that proactive maintenance is achieved, and Duffuaa and Raouf (2015) further highlight that this includes material and stocking preparation, thus allowing maintenance work to be scheduled at times that are not disruptive to production or service schedules.
Various techniques may be used to accomplish a proactive maintenance approach, and these include:

2.1.1 Predictive Maintenance

This maintenance approach utilizes historic data and skills to determine the need for maintenance work (Basri et al. 2017; Chiu et al. 2017; Zonta et al. 2020). It is considered both a time-based and condition-based maintenance approach (Duffuaa and Raouf, 2015) and has gained popularity for application on critical systems in operations and services. Predictive maintenance includes continuous monitoring of a system to avoid system failure. This maintenance approach is also praised for providing low cost in operation production (Lee et al. 2017), and Lee et al. (2015) describe predictive maintenance as a trend-oriented approach that begins with the identification of a system or component state through the use of engineering techniques and statistical tools that has capabilities of processing and analyzing such data to predict the differences between healthy and unhealthy condition of the system.

Although predictive maintenance is often criticized for its reduced frequency of maintenance by avoiding maintenance tasks that are deemed unnecessary (Lee et al. 2015; Motaghare et al. 2018), it is the only maintenance approach that ensures that complex and multi-layered systems that often take long to maintain are only opened and serviced when required.

2.1.2 Condition-based maintenance

Condition-based maintenance (CBM) is carried out based on the known condition of the equipment (Ahmad and Kamaruddin 2012; Duffuaa and Raouf 2015; de Jonge et al. 2017). Maintenance scheduling on this type of approach may be done often and is time-consuming. Prajapati et al. (2012) pins the origin of CBM to Rio Grande Railway Company in the late 1940s. According to Prajapati et al. (2012), the railway company used CBM techniques in detecting unwanted engine leaks of coolant, oil, and fuel by evaluating changes in temperature and pressure in a system. This maintenance approach was later embraced by other industries such as automotive, aerospace, military, and manufacturing (Prajapati et al. 2012).

CBM requires dynamic scheduling of maintenance activities (de Jonge et al. 2017). Although the relative benefit of CBM relies strongly on the behavior of the asset deterioration process and severity of failures, setup time, condition measurement accuracy, and the number of randomnesses that deterioration level occurs (de Jonge et al. 2017), it is criticized that it cannot be applied to all assets and often its high implementation costs might not be justified (Ahmad and Kamaruddin 2012; de Jonge et al. 2017; Ellis, 2008).

2.1.3 Reliability-centred maintenance

Asset reliability is concerned with the probability that the item will perform a required function without failing under a stated condition and stated period (O'Connor and Kleyner, 2012; Campbell and Reyes-Picknell, 2006). Typically used together with Total Productivity Maintenance (TPM), Reliability-cantered maintenance (RCM) is a time-based concept that seeks to maximize system availability whilst minimizing the frequency of downtime incidents through the management of the physical asset's Mean Time Between Failures (MTBF). Although Sherwin (2000) argues the purpose of periodic maintenance as mainly to improve safety rather than to increase availability or reduce costs, O'Connor and Kleyner (2012), and Campbell and Reyes-Picknell (2006) think that system availability is a proportion of time that an asset is available for use, and to improve availability (A), system uptime must increase and its downtime decreases, and this is represented by the formula,

$$A = \frac{(Scheduled\ Uptime - All\ Downtime)}{Scheduled\ Time} \quad (1)$$

Campbell and Reyes-Picknell (2006) argue that RCM is a proactive maintenance approach that seeks to determine, i) the type of failures that are likely to occur, ii) steps that are needed to be taken when failures occur, and iii) the process of eliminating the root cause of failures.

The pattern of asset failures often changes with time as represented in Figure 1 (Ahmad and Kamaruddin 2012; O'Connor and Kleyner 2012). This implies that the rate of failures is often high during system start-up or break-in. System failures decrease and stay constant for a period after commissioning. Wear-out failures follow at an increasing rate due to material fatigue resulting from cyclic loading.

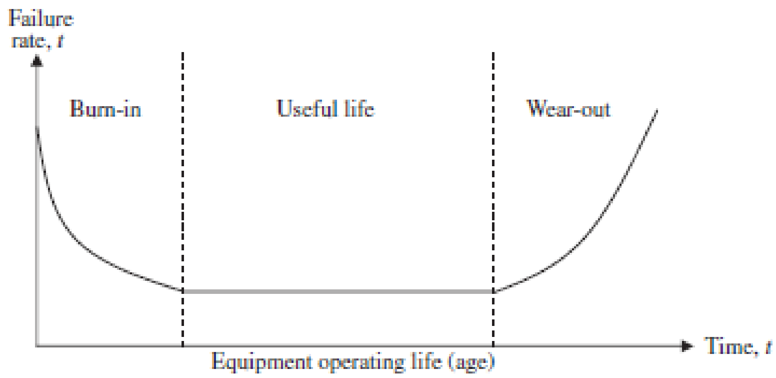

Figure 1. Bathtub curve (Ahmad and Kamaruddin, 2012)

Maintenance scheduling on the RCM approach relies on two time-based parameters: Mean Time Before Failure (MTBF) and Mean Time To Repair (MTTR) (Duffuaa and Raouf, 2015), where:

$$MTBF = \frac{Operating\ time}{Number\ of\ failures} \quad (2)$$

And

$$MTTR = \frac{Downtime}{Number\ of\ failures} \quad (3)$$

2.2 Reactive maintenance

Reactive maintenance is a strategy that is applied to reactivate physical assets that are incapable of further operations. This is both an unplanned and unscheduled maintenance strategy and is sometimes referred to as run to failure strategy. Although the reactive maintenance strategy is practiced in some cases (du Plessis et al. 2015; Özgür-Ünlüakın et al. 2019), the strategy is mostly criticized for its inherent high cost of maintenance and promoting an unsafe environment. According to Wireman (2015), there is no cost-effective service for the inventory and procurement process in a reactive maintenance strategy. But du Plessis et al. (2015) investigated the performance sustainability of a diverse Energy Management System (EMS) through reactive maintenance and concluded that there is no proportionality between the high operational availability of the system to the increased EMS performance. In contrast, Murthy et al. (2002) argue that the overall performance of an asset is dependent on its availability, and reactive maintenance causes the degradation of asset components over time, thus reducing significantly the lifespan of the asset.

2.3 Maintenance Planning and Scheduling

Maintenance planning and scheduling are key to the development of an effective and efficient maintenance program. The planning process provides details of tools, materials, and resources required to execute maintenance work, whilst scheduling deals with the prioritization of maintenance work. Planned and scheduled maintenance work improves the quality of the overall maintenance management.

There are many published research studies on maintenance planning and scheduling (Alaoui selsouli et al. 2009; Sortrakul et al. 2005; Zhou et al. 2008), and most highlight the importance of planning and scheduling for proactive maintenance. Duffuaa and Raouf (2015) concluded that the key importance of planning and scheduling is to develop an efficient maintenance management process. Meanwhile, maintenance planning deals much with the choice of work and strategic approach to the work, to ensure efficiency and quality of work (Ab-Samat et al. 2012).

Planning and scheduling maintenance on a critical asset includes the process of identifying critical aspects of the asset or production line that could cause loss of production, injury to personnel, and or even poor-quality production (Moubray 1997, Nwadinobi and Ezeaku 2018). To identify a criticality of an asset, Moubray (1997) advises that the following questions should be answered regarding the asset, and those are:

1. What are the functions and associated performance standards of the asset in its operating context?
2. In what ways does the asset fail to fulfill its functions?
3. What causes each functional failure?
4. What happens when each functional failure occurs?
5. In what way does each failure matter?
6. What can be done to predict or prevent each failure? and lastly
7. What should be done if a suitable proactive task cannot be found?

In a single-line production process, all assets on the production line might be deemed critical. But the criticality of an asset must be identified taking into consideration all other aspects such as production output, safety, quality production, or even asset value (Modarres et al. 2017). Figure 2 shows a single-line continuous process for a brick manufacturing process with a critical asset identified. In this case, an extrusion machine was identified as critical in the production of many quality bricks. The extrusion machine, sometimes referred to as the extruder machine is a type of formwork equipment that forms bricks from porous clay soil, which is premixed with water to form a wet clay. The equipment comprises the following main components,

1. A mechanical gearbox,
2. A clutch system for engaging and disengaging gear-drive
3. An electric motor, and
4. Augers for pushing the clay out of the extruder for formwork.

The other equipment, which is critical to the functions of an extruder is the mixing bathtub, sometimes referred to as the mixer machine. Although the mixer machine is a separate machine from the extruder, it is a critical intermediate feed machine to the extruder, and without the mixer machine in operation, the extruder machine will stop and thus not operate at all for production.

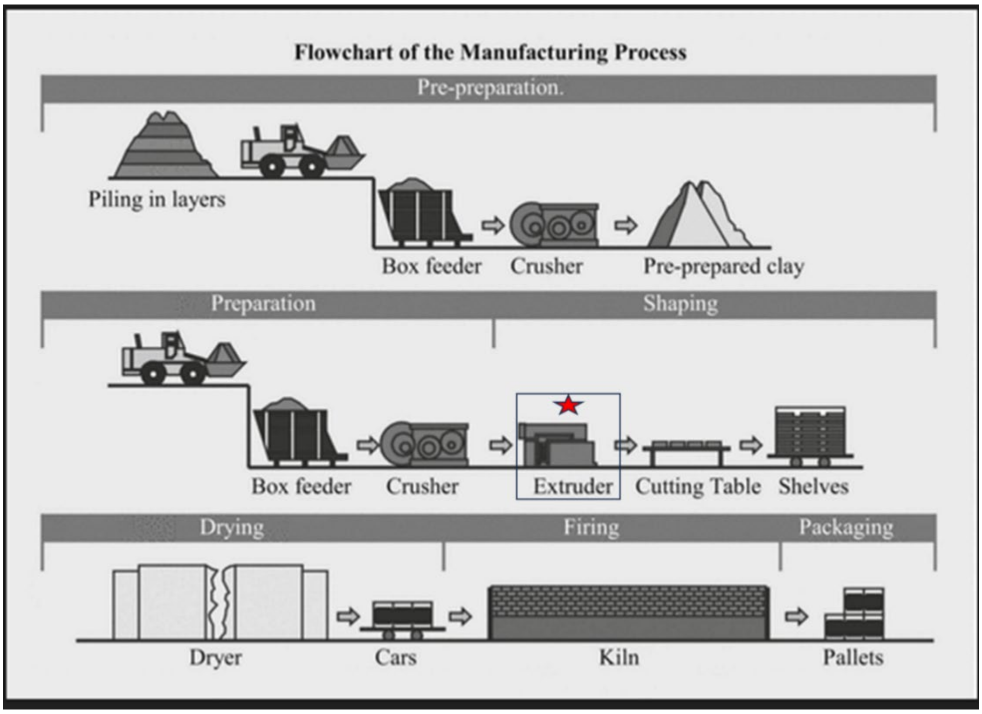

Figure 2. A brick manufacturing process with an extruder machine highlighted.

A brick manufacturing process comprises the following stages:

Clay preparation process
This is the first material preparation process after mining clay soil. This process includes the reduction of large lumps of clay to small particles using grinding the clay particles to acceptable sizes that have been determined through manufacturing quality processes.

Forming and Cutting
This is the second phase in the brick manufacturing process where prepared clay sand is mixed with water to form wet clay, which is then extruded through an extruder machine. The clay extruded from an extruder machine is in the form of a long column, and to make bricks of different sizes, a formed clay column is then cut into sizes of bricks.

Drying and Firing
Since bricks that come from forming and cutting process still have a high moisture content, the wet bricks are then dried by electric fans to the lowest moisture, closer to zero point. Upon the drying process, bricks are then fed through a kiln and heated gradually up to temperatures between 1000 – 1100 degrees Celsius. After this firing process, bricks are then ready for despatch to customers for building.

2. Research method
The study presents a case for the optimization of maintenance management plans, schedules, and overall approaches to maintenance work on a critical asset in a manufacturing process. Using qualitative data collected on the Computer Maintenance Management System (CMMS) of historic events of unplanned work that were captured between the years 2018 to 2022, the study evaluates the data through the Failure Mode and Effective Analysis (FMEA) approach to optimize the existing maintenance strategies. FMEA is a problem-solving tool that analyse and identify the failure mode on a system and assess the potential risks to it (Wu et al. 2021).
Case studies can provide many details about how processes function, and therefore, a case study was chosen as a research method to assist in the understanding of a particular event, phenomenon, or even a developed trend (Brown 2008; Yin 2009).

Case Study

Aim

The case aimed to reduce and eliminate unplanned critical asset downtime, which contributed to product quality defects in a brick manufacturing plant.

As a result of unplanned work or breakdowns on the extruder machine, which resulted in unplanned stoppages and so the quality of bricks produced, the business realized an increase in customer complaints due to poor quality bricks that were delivered to customers. In resolving poor quality issues from customer complaints, a root-cause analysis identified unplanned stoppages on an extruder machine as one of the contributing factors to the poor-quality production of bricks. Figure 3 presents five-year data on the number of customer complaints received as a result of quality defects delivered to the customer site. Due to a large number of bricks supplied to a particular customer, a customer complaint that results in a claim causes a significant loss to the business revenue, and in other instances, a complete loss of sales revenue could be realized. Although the study does not discuss the cost of poor-quality bricks, there is a positive correlation between brick quality and revenue received by the business.

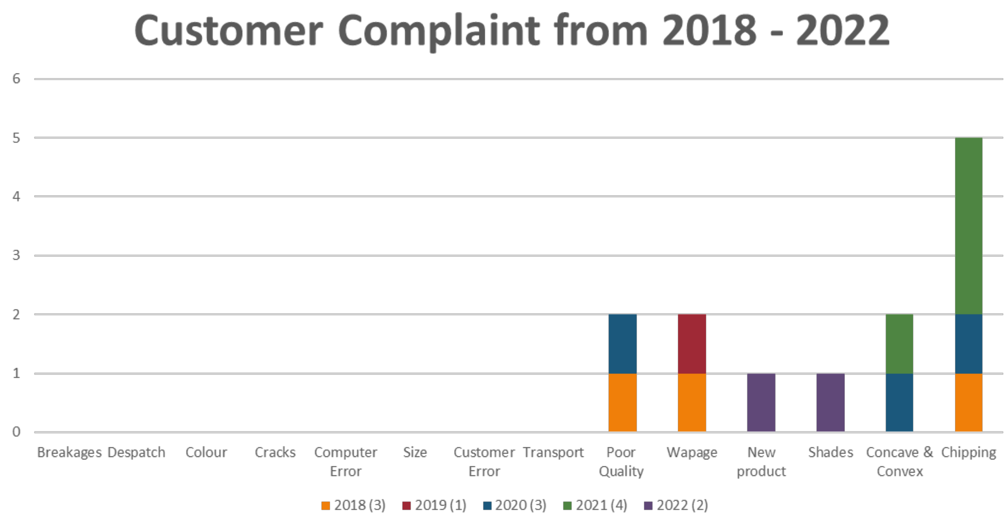

Figure 3. Number of recorded customer complaints for the period 2018-2022

Figure 4 shows the number of corrective action requests recorded between the year 2018 and 2022 for producing non-conforming or poor-quality bricks. The corrective action requests are internal control measures to avoid any repeat of quality defects and raised as a result of the quality management system on the production process to reduce or eliminate any non-conformances of bricks produced.

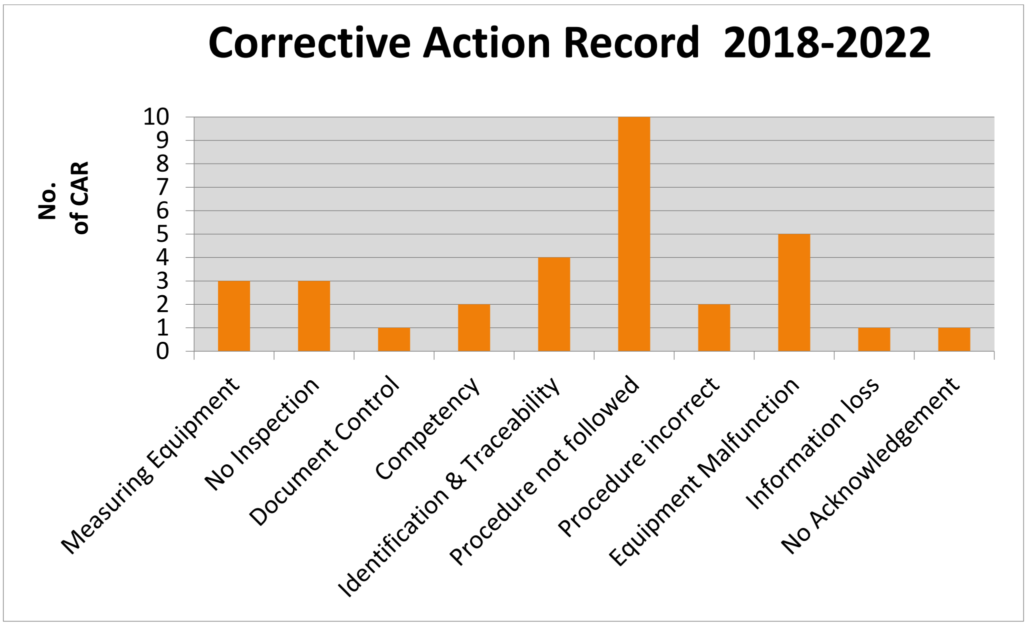

Figure 4. Number of recorded corrective action requests, internally for the period 2018-2022

4.3 Composition of planned and scheduled work on the extrusion machine before optimization

Table 1 lists planned and scheduled maintenance work on an extruder machine before maintenance optimization. The planned maintenance work and schedules were based on the original machine manufacturer's guidelines (OEM), practical assessment, user experience, serviceable life of an asset, and the historic failures on the machine. Whilst OEM's maintenance guidelines are generally conventional and time-based (Weber et al. 2005), they often do not consider an asset's operating environment and operator requirements. Therefore, combining all the guidelines to determine optimized maintenance planning and scheduling is often considered advisable.

Table 1. Current planned and scheduled work of the extrusion machine

Asset	Work Planned	Type of Work	Maintenance Technique	Schedule
(MKEX1) Extruder	Inspect gearbox and input shaft condition	Mechanical	Condition-Based	Weekly
(MKEX1) Extruder	Inspect wiring and test remote isolation switch	Electrical	Condition-Based	Weekly
(MKEX1) Extruder	Sample oil and send for analysis	Mechanical	Predictive	Half Yearly
(MKEX1) Extruder	Perform vibration analysis on the gearbox	Mechanical	Predictive	Yearly
(MKEX1) Extruder	Inspect oil level and clean magnetic filter	Mechanical	Condition-Based	Weekly
(MKEX1) Extruder	Inspect Extuder liners and replace if necessary	Mechanical	Condition-Based	Quaterly
(MKEX1) Extruder	Change Auger No. 6&7	Mechanical	Reliability Centered	Six Weekly
(MKEX1) Extruder	Change Auger No. 1,2,3&4	Electrical	Reliability Centered	Weekly
(MKEX1) Extruder	Replace swiper shoes	Mechanical	Reliability Centered	Half Yearly
(MKEX1) Extruder	Inspect motor fan	Electrical	Condition-Based	Weekly
(MKEX1) Extruder	Grease Extruder machine	Mechanical	Reliability Centered	Weekly
(MKEX1) Extruder	Inspect V-belts	Mechanical	Condition-Based	Weekly

NB! OEM GUIDELINE

Oil in any gearbox or thrust bearing assembly should be changed after the first 100 hours of operation (break-in period). Afterwards, the oil should be changed every 1,000 hours of operation. More frequent oil changes may be needed for especially humid or dirty conditions.

4.4 Unplanned maintenance work on the extrusion machine that resulted in downtime

Table 2 lists unplanned maintenance work on the same extruder machine mentioned for a period starting from the year 2019 to 2022.

Table 2. Unplanned maintenance work for Extruder machine

Month/Year	Asset	Work Order Code	Work Performed	Failure cause	Failure Type	Date	Breakdown Hours
March 2019	(MKEX1) Extruder	WO6755	Open valve at water tank	Unknown	Mechanical	2019-03-25	0,5
May 2019	(MKEX1) Extruder	WO6733	Replaced and rewired water pump	Component failure	Electrical	2019-05-26	1,5
June 2019	(MKEX1) Extruder	WO6734	Removed and cleaned up oil equipment at Extruder	Dirt	Mechanical	2019-06-04	3,0
September 2019	(MKEX1) Extruder	WO6852	Strip extruder input shaft to replace a bearing	Component failure	Mechanical	2019-09-19	8,0
September 2019	(MKEX1) Extruder	WO6904	Assembled the input shaft of the extruder	Component failure	Mechanical	2019-09-20	6,0
February 2020	(MKEX1) Extruder	WO7035	Adjust stuffing box seal	Misalignment	Mechanical	2020-02-04	0,7
March 2020	(MKEX1) Extruder	WO7830	Clean and tighten locknuts on water gauge	Unknown	Mechanical	2020-03-13	1,0
June 2020	(MKEX1) Extruder	WO7763	Reset panel	Power failure	Electrical	2020-06-17	0,2
July 2020	(MKEX1) Extruder	WO7074	Fix leaking clayfix pipe	Fatigue	Mechanical	2020-07-31	1,0
September 2020	(MKEX1) Extruder	WO7690	Fixed water leak	Fatigue	Mechanical	2020-09-06	0,5
December 2020	(MKEX1) Extruder	WO6969	Repaced failed bearing on input shaft	Component failure	Mechanical	2020-12-09	12,0
May 2021	(MKEX1) Extruder	WO8048	Replace old clutch plates	Component failure	Mechanical	2021-05-29	3,0
July 2021	(MKEX1) Extruder	WO7870	Tighten guard	Vibrations	Mechanical	2021-07-29	0,5
August 2021	(MKEX1) Extruder	WO7831	Open extruder replaced auger no1,2,3,4,5	Wear and tear	Mechanical	2021-08-17	6,0
October 2021	(MKEX1) Extruder	WO7783	Replaced worn pulley	Wear and tear	Mechanical	2021-10-03	7,0
November 2021	(MKEX1) Extruder	WO7820	Replace augers no6 and 8	Wear and tear	Mechanical	2021-11-17	5,0
January 2022	(MKEX1) Extruder	WO7905	Fault finding on the thermostat. Not working	Component failure	Electrical	2022-01-24	0,5
January 2022	(MKEX1) Extruder	WO7784	Strip and clean water valve	Dirt	Mechanical	2022-01-27	1,0
February 2022	(MKEX1) Extruder	WO7784	Cleaned	Dirt	Production	2022-02-13	0,5
April 2022	(MKEX1) Extruder	WO8014	Grease machine and refill oil	Nigligence	Mechanical	2022-04-16	0,5
May 2022	(MKEX1) Extruder	WO8021	Open up split seal augers and clean out. Throw oil into bearing on pug shaft	Blockage	Mechanical	2022-05-02	3,0
August 2022	(MKEX1) Extruder	WO8030	Clutch not opening and found air pipe torn	Wear and tear	Mechanical	2022-08-09	1,0
November 2022	(MKEX1) Extruder	WO8042	Replaced broken swiper knife	Excessive force	Mechanical	2022-04-16	2,0

5. Data analysis for Maintenance optimization

Whilst planned and scheduled work for proactive maintenance of the extrusion machine were derived from OEM's advice, practical assessment, user experience, serviceable life of an asset, and the historic failures on the machine, there were noticeable disparities in terms of unplanned work that could have been prevented through planned and scheduled work. This warranted an optimized planned and scheduled work to reduce unplanned work or the number of hours in unplanned work. To do that, extensive failure mode and effect analysis (FMEA) was conducted on each of the unplanned maintenance work highlighted in Table 2. In this case, unplanned or reactive maintenance work that took a duration, of more than 1 hour was highlighted and action plans to reduce reactive work hours or eliminate recurrence were drafted and implemented, which resulted in the adoption of the following optimized proactive strategies for implementation:

September 2019	(MKEX1) Extruder	WO6852	Strip extruder input shaft to replace a bearing	Component failure	Mechanical	2019-09-19	8,0
September 2019	(MKEX1) Extruder	WO6904	Assembled the input shaft of the extruder	Component failure	Mechanical	2019-09-20	6,0
December 2020	(MKEX1) Extruder	WO6969	Repaced failed bearing on input shaft	Component failure	Mechanical	2020-12-09	12,0

Bearings that hold the input shaft and pinion gear are prominent to failures in an extruder machine. This often happens when, i) the machine is overloaded, ii) bearings are not adequately lubricated (oil lubrication in this regard), and lastly, iii) when the locking mechanism (locking nut) of the bearing becomes loose.

Predictive maintenance for input shaft bearings was added as a proactive maintenance strategy to predict any change in conditions from normal to abnormal conditions during machine operation. This optimized approach to the currently planned maintenance tasks was performed by,

i) installing an electronic detection unit to detect, the speed of the input shaft, the temperature of the bearing, and lastly the vibrations frequencies of the bearing.
ii) by monitoring the load on the gearbox during operation and curtailing any excessive load.

1.

May 2021	(MKEX1) Extruder	WO8048	Replace old clutch plates	Component failure	Mechanical	2021-05-29	3,0

Whilst a clutch plate is a wearable material over a period, its wear rate can be predicted, and the condition of the clutch plate can be monitored. Both the maintenance approach, which is predictive and condition-based were evaluated against, i) availability and access to predictive tools that are readily available in the market for predicting clutch plate wear rate and ii) the amount of time required due to the complexity of the assembled clutch system, to disassemble and assemble the clutch mechanism to assess the wear part.

The reliability-centered maintenance approach was adopted for optimization of the maintenance task to ensure that the clutch plate is replaced based on the specified extruder runtime, in this case, 8500 hours of clutch operation was adequate before replacement. Figure 5 indicates an extruder machine runtime data as captured through a SCADA system to assist with capturing periodic data for reliability-centered maintenance. Although (Sherwin 2000) argues the increased costs of the reliability-centered maintenance approach, it is advisable to consider the overall cost of implementing this approach against the benefits that can be derived.

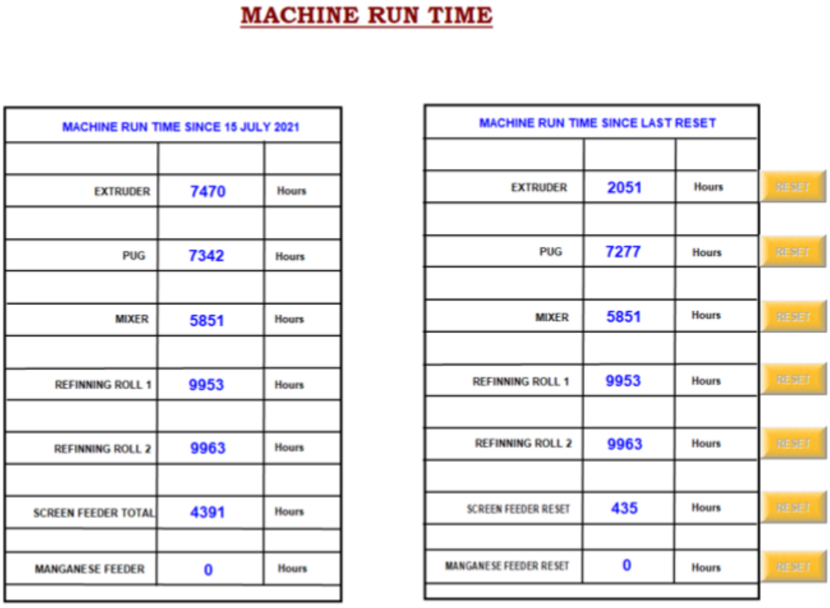

Figure 5. Machines Runtime captured through SCADA system.

2.

May 2019	(MKEX1) Extruder	WO6733	Replaced and rewired water pump	Component failure	Electrical	2019-05-26	1,5

The motor-driven pump is a mechanical component used to transfer a fluid medium from suction to a delivery point. A pump contains rotating parts such as an impellor, bearings, and a shaft, and is often mechanically attached to an electric motor through the shaft. As a result of fatigue and excessive loads, rotating mechanical components on the pump are often subjected to wear and tear, or loading failures. The same applies to an electrically powered motor that is used to mechanically power the pump.

A hybrid approach, that is CBM and TBM for proactive maintenance of the pump and motor was adopted. This includes a quarterly vibration analysis of the pump, a yearly change of pump bearings, and an inspection of impellor size and electrical current monitor on the motor to identify any load change.

3.

August 2021	(MKEX1) Extruder	WO7831	Open extruder replaced auger no1,2,3,4,5	Wear and tear	Mechanical	2021-08-17	6,0
October 2021	(MKEX1) Extruder	WO7783	Replaced worn pulley	Wear and tear	Mechanical	2021-10-03	7,0
November 2021	(MKEX1) Extruder	WO7820	Replace augers no6 and 8	Wear and tear	Mechanical	2021-11-17	5,0
November 2022	(MKEX1) Extruder	WO8042	Replaced broken swiper knife	Excessive force	Mechanical	2022-04-16	2,0

Although these breakdown failures should not have happened as they are included in the proactive maintenance strategy, this has displayed one of the disadvantages of the reliability-centered maintenance approach, particularly when a balance has to be made between increasing maintenance cost versus machine runtime. Extruder augers are very much exposed to the type and geological properties of clay soil in use, and therefore their wear rate differs in that regard. Whilst condition monitoring of the augers could be difficult during machine operation because of their location, condition monitoring can also take longer if planned and scheduled due to the accessibility of the augers from the machine.

Reliability-centered maintenance approach was found to be an excellent proactive strategy for the task, with augers being scheduled to be replaced after every 1500 hours of operation. Further evaluations and investigations were needed to reduce the increasing cost of auger replacement. Such evaluations and investigations include,

i) investigating more durable material for auger construction or casting,
ii) improving the plasticity of the clay sand,
iii) a better understanding of the wear rate of the auger based on different clay sand materials.

4.

June 2019	(MKEX1) Extruder	WO6734	Removed and cleaned up oil equipment at Extruder	Dirt	Mechanical	2019-06-04	3,0
May 2022	(MKEX1) Extruder	WO8021	Open up split seal augers and clean out. Throw oil into bearing on pug shaft	Blockage	Mechanical	2022-05-02	3,0

Often engineering maintenance work is solely done by engineering personnel. Sometimes in an attempt to balance business resources, i.e., material, labor, and other costs, it is often easier to reduce labor costs and reorganize the operation so that it operates optimally. Redistributing responsibilities in this regard becomes necessary to distribute the amount of workload in the business.

To achieve the reliability of assets and the quality of products, whilst maximizing the overall efficiency of labor, Total Productivity Maintenance (TPM) becomes necessary to implement to achieve the set objectives. TPM is part of the Reliability-centered maintenance approach which uses the following strategies (Nakajima 1989):

- Establishment of a thorough system of preventative maintenance for the entire asset life span,
- Cross-functional approach to preventative maintenance, which includes utilizing engineering, operators, and production manager for executing maintenance tasks.
- Promotion of preventative maintenance through the motivation of management and autonomous small group activity.

To optimize proactive maintenance tasks that are linked to cleaning and oil refill, a TPM approach was adopted. This approach assisted with the increase of knowledge of the machine and overall process amongst operators and production managers. Díaz-Reza et al. (2019) highlight that TPM is a tool that can be used to maintain an asset used in a production process to an optimal condition, whilst providing a product of the best standard that exceeds customer's expectations. According to Díaz-Reza et al. (2019), TPM seeks to reduce waste, minimize equipment inactivity, and improve quality, it also focuses on asset maintenance programs that optimize the efficiency and performance of the equipment.

5.1 Breakdown Hours Measurement on the Extruder Machine

Figure 6 shows the yearly accumulated machine downtime for unplanned maintenance in a bar graph format for the period 2019 to 2022. An improvement in downtime on the extruder machine can be noticed in the year 2022. The reduction in downtime hours in the year 2022 are attributed to improved availability of the extruder machine as a result of optimized maintenance planning and scheduling.

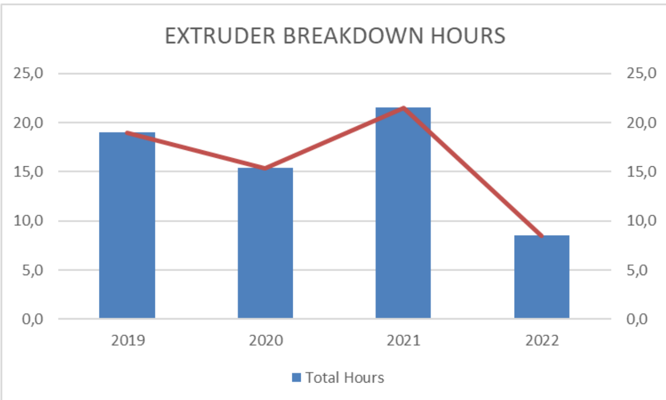

Figure 6. Historic counts of downtime hours for the period 2019-2022

Conclusion

An effective maintenance planning and scheduling program is a dynamic process that requires constant optimization. It is very important that such a program continuously evaluate system failures against available resources for the improvement of asset reliability. Such a program must be better at preventing failure recurrence whilst extending the lifespan of the system or asset.

A combination of time-based, and condition-based approaches to maintenance planning and scheduling could be successful in preventing failure recurrence and optimizing the maintenance program. An extended evaluation of data provided through condition-based could assist in optimizing maintenance tasks and scheduling thereof tasks. Unnecessary maintenance tasks often result in inefficient utilization of resources, and this leads to increased maintenance costs.

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