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RELIABILITY INVESTIGATION OF METCOPPO SHEET PRODUCTION MACHINE

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Abstract

The reliability of a "Metcoppo sheet production machine" used in an aluminum production line was assessed in this study. The reliability of the production line's units was analyzed using Root Cause Analysis as a maintenance tool. The severity of the underlying cause of an equipment or component failure determines the maintenance strategy that is assigned to a production line. Evaluations were conducted on the instrumental, direct, and root causes of failure. The investigation was conducted using the Metcoppo sheet production machine. The findings revealed that while management, staff, procedure errors, and delays in critical spare parts accounted for the least amount of production line failures, [redacted] equipment and maintenance issues accounted for the majority. Findings revealed that the production line has high availability, reliability and quality. MATLAB programme and Excel spreadsheet were adopted to evaluate the results. Research suggests that there could be decrease equipment failure, decrease production line downtime,

Keywords:
Metcoppo machine, production line, reliability

increase reliability and availability, improve product quality, and an improvement in workers' morale, environmental safety, energy savings and customer satisfaction if a sound maintenance philosophy is used.

Introduction

These days, companies are established to meet customer satisfaction by the production of quality products aligning the aims and objectives to attract market demands. The production industries shall continue in business and optimal if the production machinery/equipment is reliable and of good quality. Production equipment during operations is faced with failures such as breakdown, misalignment, crack, wear and tear, etc. Hence, a good maintenance strategy is explored to improve productivity and also avoid machine downtime, low product quality, industrial hazards, etc. (Sharma et al., 2003).

To truly achieve excellence in machinery maintenance, availability, and reliability assessment of the production equipment, an appropriate approach view is required. The traditional maintenance, availability, and reliability assessment (MMAR) should be expanded to include: business and work process MMAR and an empowered workforce of engaged employees.

The cost of the unavailability of critical equipment or its failure is a major factor in any productive organization. Hence, failure analysis remains a better method of the maintenance management of critical equipment that is the focus of this research.

The Aluminium production line has been producing below maximum capacity due to challenges embedded in the control panel, gearbox, hydraulic motor, pneumatic pump failure, etc, of the production functions. These have affected the efficiency of the production unit. In order to minimize these failure challenges, a comprehensive analysis of the production equipment failure rate causes of failure and devise the best technique to reduce these failures. Failure, as it relates to the production line, connotes that the equipment is unable to meet the company's production targets. The maintenance management key roles include: corrective maintenance and preventive maintenance (PM). The maintenance team of the various departments carries out daily/routine plant maintenance checks. In addition to the equipment daily checks, the maintenance section and the vendors carry out scheduled maintenance and overhauling every 420 hours. A monthly diagnosis of the vibration, speed, throughput/, and state of the lubrication oil is evaluated by the maintenance department.

Reliability of Production Line

Black (2007) describes a production system as the arrangement of tangible elements (information system, material-handling equipment, and people) characterized by measurable parameters.

The stages in a production line include procurement, fabrication, assembly, testing, packaging and distribution. The production line in an industry could be categorized into three groups i.e., automated production lines, semi-automated production lines and manual production lines (Subramaniam et al., 2008).

Machine Failure

Machine failure can be defined in a variety of ways. For example, it can be the difference between the target and current level of performance, a deviation from the standard or desired performance, or an unfavorable outcome of a job (Anandh *et al*., 2014). In other words, failure can be defined as the difference between the actual and expected outcomes of a system. The operational efficiency of any manufacturing company is negatively impacted by machine breakdowns. In a traditional manufacturing system, it can be challenging to identify significant failures and investigate their relationships with other process factors (Ahmad *et al*., 2018).

Component Reliability

The Industrial fields, particularly the ones in production, possess the equipment needed to promote the development of a seamless production flow. These machinery are made up of parts that are necessary for carrying out routine operations (Sajaradj *et al*., 2019). Most organizations now strive to mitigate the tendency of production to be discontinued, with malfunctioning machinery as one of the major challenges. One of the techniques that this breakdown is minimized in frequency is carrying out maintenance operations (Widyaningrum & Winati, 2022). Salimah *et al.* (2023) developed a model that combines the needs of components and subsystems with the vital maintenance aspects.

Literature Review

Today's technological equipment/machines in manufacturing industries are faced with a high level of complexity. The need for an availability and reliability study of such machines is very much desirable. The maximum output of production items/components/equipment could be possible by ensuring minimum shutdown and breakdowns to ensure reduction of the unavailability and increase in the reliability of the machines. However, the first stage in reliability development is gathering and assessment of the available and right data. The following reliability approaches of the metcoppo machine were investigated; Condition-Based Monitoring, Failure Mode and Effect Analysis, Fault Tree Analysis, Root Cause Analysis and Vibration Analysis amongst others.

The essence of reliability analysis in any engineering system is a failure free environment, which should be obtained as economically as possible. The first reliability studies came out of the aircraft industry during World War 11. In the 1960s as systems became more complex, new analysis methods were required.

Bruce (2004) submitted that complete appraisal of reliability needs the quantitative estimate of three different classes of failures such as; event related, early life and wear out. The early life could be infant mortality that constitute of relatively defects introduced in production operations. Wear out failure are found due to prolonged expensive to environmental and operating stresses and could be found in the overall population of items if in production process for long.

Daniela et al. (2003) used a Monte-Carlo simulation through Excel spreadsheet to examine the reliability of a geothermal power plant. This simulation approach made use of the strong mathematical and statistical capabilities of Excel. According to Neville (2004), in his investigation about failure analysis opined that combining effective failure analysis with a good predictive maintenance programme could be beneficial. This could be obtainable depending on the type of facility; this could optimise maintenance costs by 20% and also increase production.

According to Baringer (2006), before reliability improvement of equipment could be defined, emphasis was based on improving the people, process, procedures and finally improvement of component reliability where the need arise. This was demonstrated with a centrifugal pump showing how engineers want to attack components for improvement while gains were achieved by knowing the people challenges, the process/procedures adopted in monitoring the best operating range, and how engineers should know the grade of installation and use characteristics to get the system installed and operating correction for reliability area.

According to Keith et al. (2008), reliability is a strategic resource which has single point accountability for providing the long-term business strategy that ensures production capacity, product quality, and best life cycle cost. Its provides proactive leadership style, direction, single point accountability, and skilled personnel needed to sustain optimal reliability, tool life, and life cycle cost for a facility's assets, and its operations.

According to Mark (2004), in his investigation revealed the process point most often used in reliability and risk assessment. Short and long terms characteristics for the point process used as models for reparable system are introduced as opposed to the long term means that a process is observe during an interval by a time close to the mean of the respective underlying distribution. According to Marina (2012), in his research in analyzing the reliability of manufacturing processes in machinery, explored corrective approach for faults removal in manufacturing industries by using FMEA as a model for the elimination of failure and quantitative assessment of operation process. Cimen and Soyal (2016) investigated on production flexibility and inventory management, random companies were evaluated to gain competitive advantage and was revealed that factors such as; shorter product life-cycle and delivery time, technological advancement and competition causes internal and external uncertainties. The findings recorded from the thermowells failure in feed gas supply downstream pipeline at a natural gas production plant revealed that the subject premature failure of the thermowells is caused by fatigue damage, due to wrong selection of thermowell design for the projected operation condition (Abdel et al., 2013).

According to Pavan et al. (2013), in investigating the Root Cause Analysis of bowl-mill pinion shaft failures illustrated the investigation of metallurgical that was examined on a breakdown pinion shaft in analyzing the failure cause. Fractography showed crack introduction from the keyway area. Mechanical testing showed that the yield strength of the material is less than the specific value.

According to Gys and Abdulmoshsin (2013), in the study on failure mode of a conveyor pulley shaft, a critical review of the failure root cause was attained. Some methodologies like: optical and scanning electron microscope analysis, visual examination and chemical analysis of the component/equipment and mechanical tests were adopted. A finite element analysis was also examined to get the stress movement in the shaft. It was gathered that the shaft failed due to fatigue and the failure was caused by poor reconditioning of the shaft during routine overhaul.

According to Arindam et al. (2013), in their investigation of how handling of equipment abuses causes premature bearing failures, indicated that the bearing failed by seizure. The dent found on the seal during handling likely led to a cascade effects-cage damage, impaired rolling, frictional increase in temperature, lubricant degradation ultimately resulting to the complete seizure of the bearing itself. Under ideal conditions of usage, most rolling bearings can survive up to their predicted fatigue life. TPM is seen as a major tool and strategic plan apply in production line which aims at optimizing equipment efficiency and reliability (Jafari et al., 2014).

Burhanuddin et al. (2014), in their investigation to analyze the reliability analysis of failure data in determining the risk factor on a repairing system, made use of maintenance planners and supervisors in deducing their results. Their work centered on the features of the machine/plant failures. The study summarized that well management of risk factor reduced repair time, and reliability of the item/component/equipment/machine. Deka et al. (2018), in their investigation on the breakdown and reliability analysis in a process industry, deduced that modern machines failures are mainly caused by their complex nature which could lead to low output. Pareto analysis, RCA and Weibull reliability measures were used in their findings.

Chlebus and Sylwia (2016) investigated in finding the cause of productive performance in manufacturing processes considered numerous requirements and factors like using existing reliability measures and review of previous work in reliability concept. According to Stenstrom et al, (2016), the theory of reliability is so vital under advancement view, for the fact that it is necessary to evaluate the actual productive capacity and economic gains of machinery in reliability economy.

According to Rahbi et al. (2017), investigated the reliability of rodding anode plant in aluminium industry, it was noticed that the production operation of raw aluminium passes through various stages. Any of the stages unavailability could results to system downtime exception of the butt and thimble removal press stage due to its parallel standby connection unless both fail. Data were gathered for some years for the analysis. Various maintenance measures viz: mean time to plant failure (MTPF), plant availability, busy period of technician and expected number of repair were collected and evaluated. The investigation adopted the Semi-Markov and regenerative point techniques for the failure analysis.

Okwuobi et al. (2018) presented the breakdown variation in an automated production using reliability-centered maintenance (RCM) as methodology. The aim was to improve the system productivity. Individual section-forming machine (ISM) of a glass blowing plant was adopted as the case study. Data were collected from the procedures in identifying the system's critical components using FMEA as maintenance best tool. Findings revealed that, there was increase in the machine's availability, safety and cost optimization with the recommendation of preventive maintenance (PM) and the methodology used. Balaraju et al. (2018), investigated on the reliability of Load-Haul-Damper (LHD) in an underground coal mine. The research showed that regular and random occurrence of failures in a machine could result to plant poor performance. For such plant to perform efficiently there is need for total overhauling. They adopted the maximum likelihood analytical estimation process and the graphical process as the reliability tools. Bansal and Tyagi (2018), in their investigation on the reliability analysis of screw manufacturing plant, submitted that production systems constitute subsystems operating in series which failure hardly occurs simultaneously. They adopted the Boolean algebra method and orthogonal matrix as their model. Lopez-Campos et al. (2018), in their findings on the reliability assessment approach for large manufacturing multifunctional machine used certain investigating tools which includes; Reliability-Center Maintenance (RCM), a combination with the Universal Generating Function (UGF) in a severe condition. Their result showed each component features during production operation.

Wang et al. (2018) presented the reliability of automobile engines using the proportional hazards model (PHM) and its variants and conditional interference tree. The findings show that the reliability, quality and availability of most automobile engines are due to age, early breakdown and maintenance history. Djassemi and Scifoddini (2019) investigated the effect of critical machine reliability improvement on productivity in manufacturing cells, emphasized that machine reliability cause be focus during manufacturing cells functional operations. The discrete-event simulation model was the technique used. Four systems major policies were surveyed in the simulation process. It was concluded that for production to be improved with optimality, more resources should be provided by the maintenance personnel's during production operations.

Methodology

This research adopted some reliability tools, which include statistical probability using Microsoft Excel spreadsheet and MATLAB to analyze and evaluate the failure data. This research made use of theoretical and analytical techniques in analyzing the causes of failure and failure rate, which were not adopted in the literature review. The research work adopts the guidelines granted by the U.S. Department of Energy (DOE Order NE-STD-1004-92), including handling, processing and reporting production data for failure analysis. The techniques adopted are desk and survey research. The survey techniques include the study of an aluminium production line in Kaduna, and a review of relevant documents; the necessary dates and time associated with failure were carefully investigated. The following were relevant documents reviewed:

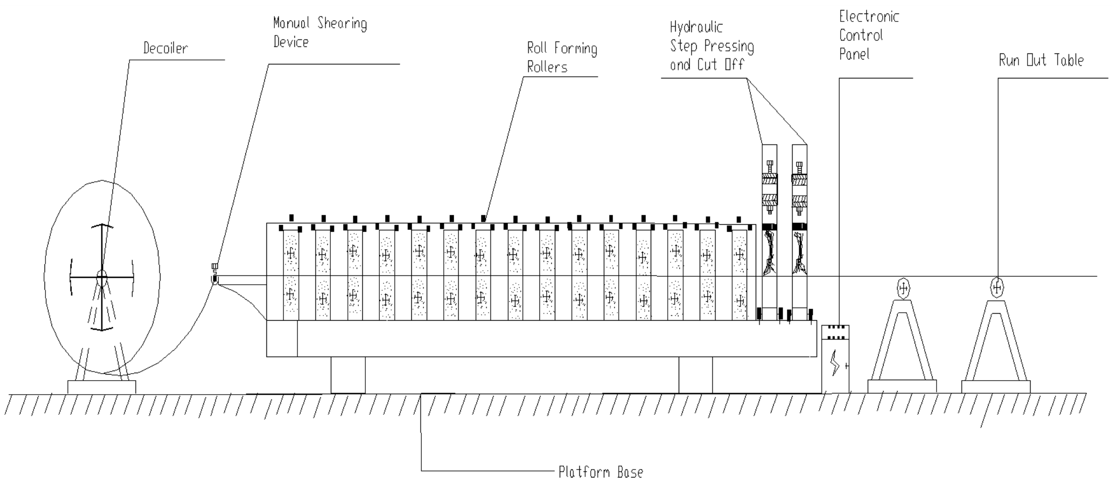
i. Operating log/company corrective maintenance log books.
ii. Inspection records.
iii. Maintenance records.
iv. Technical meetings minutes.
v. Company annual report sheets.
vi. Procedure and instructions.
vii. Work orders.
viii. Manufacturer data sheet.

The desk work involves referencing technical papers, engineering journals and text relevant to this study. The text includes; Engineering design Handbooks and Reliability, Handbooks on maintenance, operations and maintenance manuals on Equipment Production Lines. Root cause analysis guidance documents, etc. analysis and calculations were focused on Aluminium company data collected. The research and desk survey were matched together to generate a final demonstration of the causes of equipment failure and the aluminium production line failure rate.

Metcoppo Sheet Production Machine

The Metccopo roofing sheet machine has a dimension of $250.2 \times 103.1 \times 50cm$. It is made of a conveyor system, hopper, roller, frame, cam, actuated cutter system, frame, 2d.c motors, control panel etc. the equipment operation involves many stages. (See figure 3.2) The schematic diagram of the Metcoppo production line. The major causes of failure of the metcoppo tiles machine production line were identified as follows:

i. Material Requirement planning (poor inventory).
ii. Gear box shutdown as a result of vibration sensor unreliability.
iii. Shutdown due to total loss of electric power.
iv. Lack of training for local manpower.
v. Failure of decoiler.
vi. Failure of proximity sensor on cutting device.



Metcoppo Tiles Production Line (Source: Survey).

Table 1: Material Requirement planning (poor inventory).

Management Problem Sub-groups	I	II	III	IV
6A – Poor administrative control	I			
6B – Organizational policy/planning deficiency	R			
6C – Poor equipment/operators supervision				
6D – Inadequate resource allocation				
6E – policy not adequately enforce				
6F – Top management problem				

Rate each sub-group cause

D – Direct Cause.

I – Instrumental Cause.

R – Root Cause.

Cause Description

6B – Improper organizational work policy/planning

i. Lack of teamwork amongst various work places which could hinder critical spare parts delivery to the offshore facility.
ii. Company's inventory data are not carefully handled and updated by maintenance personnel; hence, tracking critical spare parts became difficult.

Recommended Corrective Actions

i. An integrated system and plan be made available to ensure coordination amongst various work places.
ii. An experienced store keeper is employed to control the inventory data.

Table 2: Gear Box Shutdown As a Result of Vibration Sensor Unreliability.

Equipment Problem Sub-group	I	II	III	IV
1A - Defective or failed component				
1B - Defective or failed material				
1C - Defective weld, braze or solenoid joint				
1D - Electrical or instrument noise		R		
1E – Error in manufacturer in supply				
1F – Contamination				I

Rate unit sub-group cause
D – Direct Cause.
I – Instrumental Cause.
R – Root Cause.

Cause Description

1D - Electrical or instrument problem

The vibration sensor might not have been installed properly and was covered with oil particulates and debris.

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Recommended Correction Actions

i. The vibration sensor should be installed properly by the service provider.
ii. Predictive and preventive maintenance approach should be carried out periodically on the vibration sensor.

Table 3: Shutdown Due To Total Loss of Electric Power.

Procedure Problem (Technology) Sub-groups		I	II	III	IV
2A –Defective or inadequate procedure		R			
2B – Lack of procedure			D		
2C – Error in equipment selection	I				
2D – Verbal communication problem					

External problem
Rate each sub-group cause
D – Direct Cause.
I – Instrumental Cause.
R – Root Cause.

Cause Description

2A –Defective or inadequate procedure

I. The turbo generator tripped because of earth fault which led to total power outage on the production machine which invariably results to total shutdown.

Recommended Corrective Action

i. There should always be a standby turbo-generator to avoid machine unavailability in production; the turbo-generator could also be undergoing scheduled maintenance during such failure.

Table 4: Lack of Training for Local Manpower.

Training Deficiency Sub-groups		I	II	III	IV
5A –Inadequate practice or hands on experience		R			
5B – Inadequate trainers	I				
5C – Insufficient content					
5D – Insufficient refresher training		D			
5E – Inadequate presentation of training materials					

Training deficiency

What is the reason training deficiency a cause?

Rate each sub-group cause

D – Direct Cause.

I – Instrumental Cause.

R – Root Cause.

Cause Description

5A –No provision for training

i. Inadequate training and certification of the local manpower by the manufacturer.
ii. Due to the unrest in the Niger Delta region, expatriates were afraid to come into the region which makes planned/scheduled maintenance difficult in production industries.

Recommended Corrective Action

i. Local manpower be adequately trained and certified by the vendor.

Table 5: Failure of Decoiler.

Equipment/Material Problem Sub-group	I	II	III	IV
1A - Defective or failed part	R			
1B - Defective or failed material				
1C - Defective weld, braze or solenoid joint				
1D - Electrical or instrument noise		D		
1E – Error in manufacturer in supply				

What is the reason component/material problem a cause?

Rate each sub-group cause

D – Direct Cause.

I – Instrumental Cause.

R – Root Cause.

Cause Description

1A - Defective or failed part

i. Rubber seal damaged in the lock-nut on the main shaft.
ii. Contamination in the cylinder and valve.

Recommended Corrective Action

i. Cylinder, valve should be free from contaminated particles, drive system should be free from shop dust and debris.

Table 6: Failure of Proximity Sensor on Cutting Device.

Equipment Problem Sub-group	I	II	III	IV
1A - Defective or failed component		R		
1B - Defective or failed material				
1C - Defective weld, braze or solenoid joint				
1D - Electrical or instrument noise				D
1E – Error in manufacturer in supply				
1F – Contamination			I	

What is the reason equipment problem a cause?
Rate unit sub-group cause
D – Direct Cause.
I – Instrumental Cause.
R – Root Cause.

Cause Description

1A - Defective or failed part

i. Setting-up or programming error, machine vibration or shock.
ii. Influence of high temperature, poor shop floor or metal environment.

Recommended Corrective Action

i. Reduction of the sensing distance, realign the system or adhere to the instruction sheet supplied with the sensor.
ii. Eliminate the source of radiated heat or protect the sensor casing with a heat shield.

Refer to analytical models for the Metcoppo sheet production line to Appendix B.

Tables 20 to 24 show the total operating hours of the Metcoppo sheet production line for the month of July to October.

Results and Discussion

Results of data gathered and evaluated from the Metcoppo Tiles production machine are presented and discussed. Tables 7 and 8 revealed the analytical findings gotten from the corrective maintenance records, metcoppo tiles machine field survey, log books of the maintenance department of an Aluminium company in Kaduna.

Table 7: Worksheet Summary for (MC2).

S/No	Problem/Deficiency Group	No. of Occurrence	Expressed in %
i.	Equipment/material	3	50
ii.	Training deficiency	1	16.6
iii.	Management problem	1	16.6
iv.	Procedure problem	1	16.6

Results of the metcoppo tiles machine production line data collected show that the problem/deficiency grouping occurs six times, out of which the equipment/material group occur trice, while training deficiency, management problem and procedure problem occur once. The grouping is presented in pie chart (see Figure 4.4).

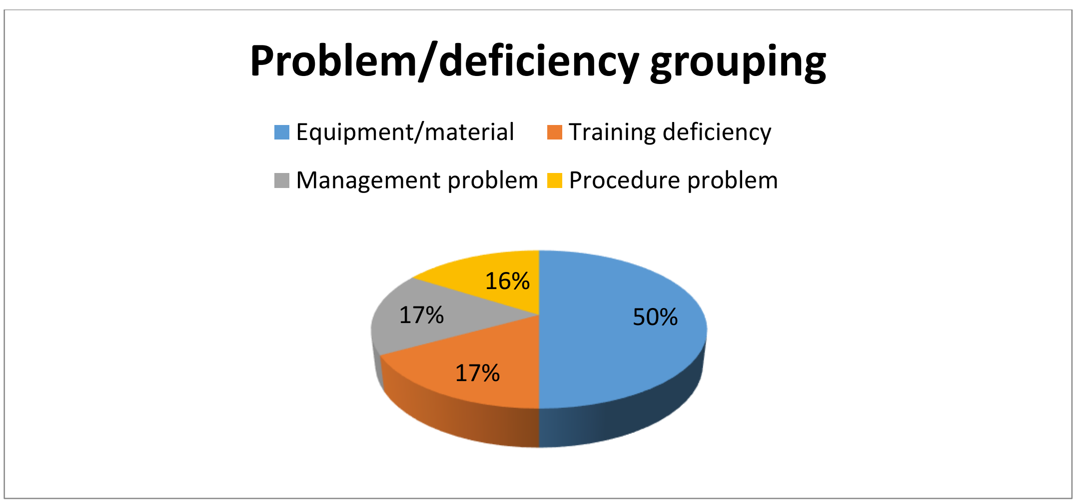


Figure 2: Deficiency grouping of Metcoppo tiles machine for July to October 2024.

Figure 2 is a pie chart displaying the percentage of the problem/deficiency grouping. The research shows that equipment/material deficiency was highest 50%, training and management problem 17% each due to inadequate administration, technical knowhow and unplanned downtime while procedure problem was seen as the least with 16%.

Table 8: Key Performance Indicators (KPI) for (MC2)

		PARAMETERS				
S/NO/ MONTHS	MCQ (%)	MTBF (HRS)	FAILURE RATE λ (%)	MTTR (HRS)	AVAIL-ABILITY(%)	RELIA-BILITY(%)
1. July	99	21.62	4.6	6.37	77	75
2. August	99	37.69	2.7	8.3	80	80
3. September	99	22.37	4.4	5.62	80	78
4. October	99	36.8	2.71	7.2	84	82

Table 8 illustrates that the plant availability is a demonstration of the general operation of the metcoppo sheet production machine show 77% for the month of July and 84% for the month of October respectively. The metcoppo machine availability is highest at 84% for the month of October, while the lowest were recorded for the month of August (80%) and September (80%). The value for the month of August and September were lowest due to schedule maintenance of the metcoppo sheet production machine. The average plant availability is 80.25% which conforms to international standards.

Discussion of Results

Key Performance Indicators (KPI) of MC2

Table 8 indicates that equipment/material problem constitute 50% of the causes of failure of the Metcoppo tiles production machine which is found to be the major cause of failure. Training deficiency, management problem, and procedure problem constituted 49.8%, due to of work organization/planning deficiency and poor administrative control.

The failure rate for the month of July is 4.6% while that of October is 2.71. The lowest was in August which is 2.7% while the highest was recorded in July which is 4.6%. The failure rate average is 3.6% for the period covering July to October that is four months. The MATLAB plot of MTTR of the Metcoppo production line against months of the year is clear in Figure 3.

Mean time to repair of metcoppo machine vs. months of the year

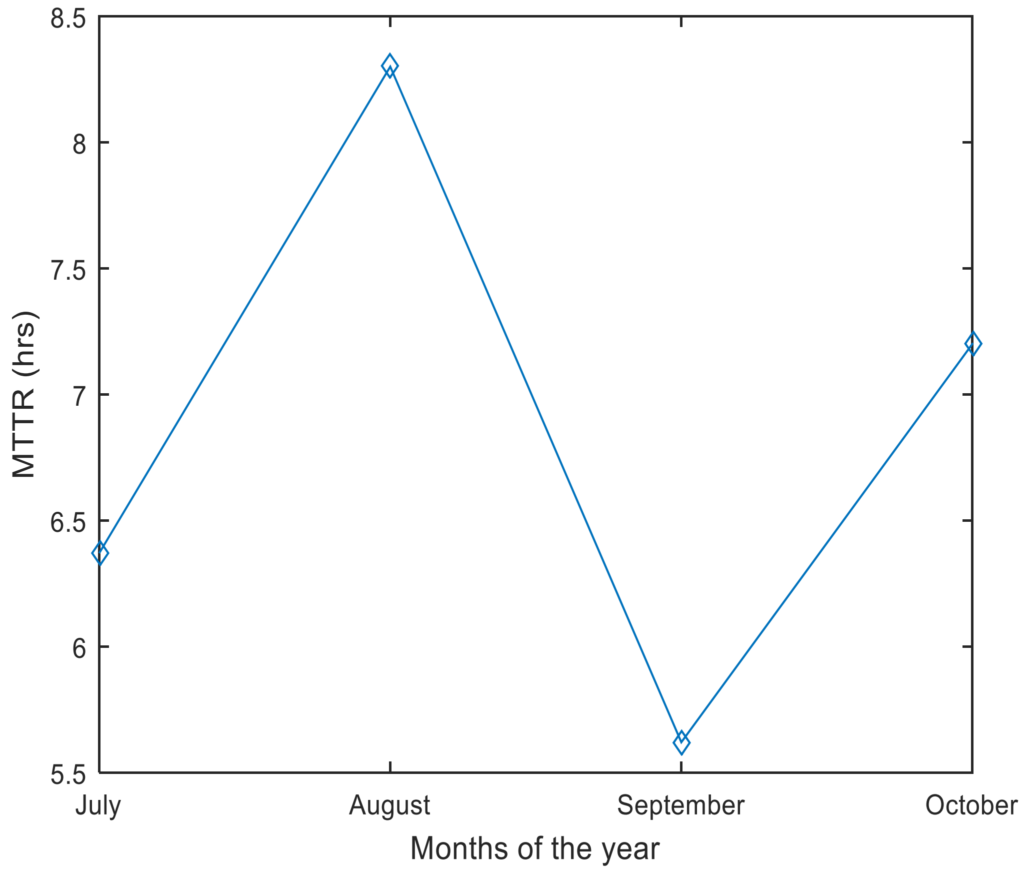


Figure 3: MTTR of Metcoppo machine for months of July to October.

The Mean Time to Repair (MTTR) as shown in figure clearly reveals two larger figures of 8.3hrs for the month of August and 7.2hrs for the month of October. The lowest MTTR was recorded in the month of September ($5.62 hrs$). The MatLab plot of the mean time before failure (MTBF) show that the highest MTBF was seen in August (37.69 hrs), while the least was obtained in the month of July (21.62 hrs.) see figure 4. The MATLAB plot was also used to represent the metcoppo machine production line in figure 5.

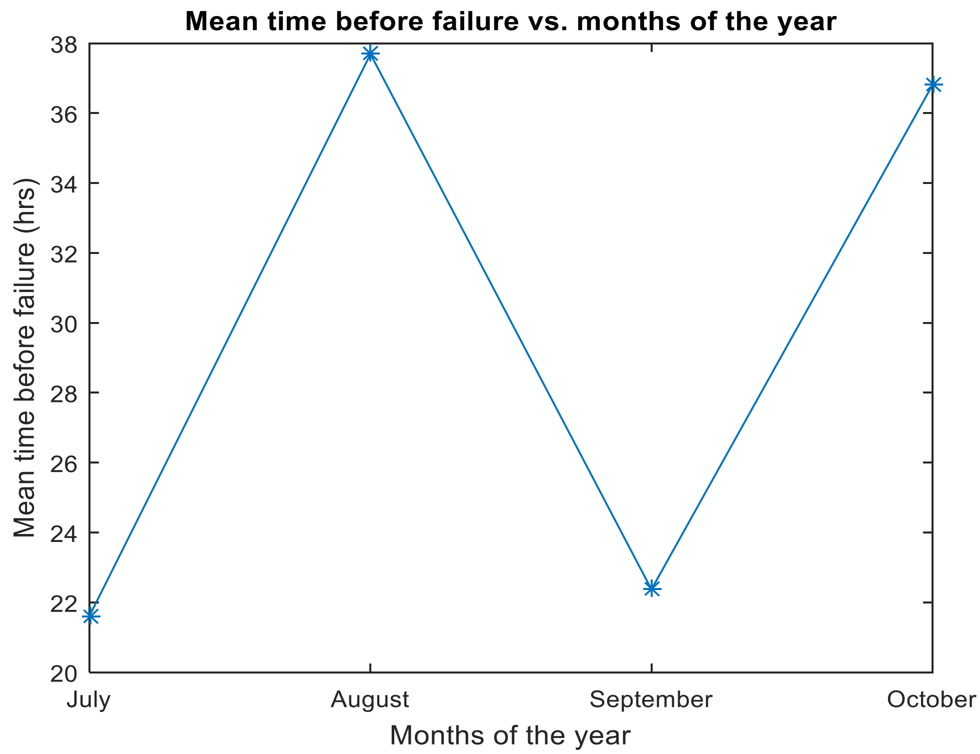
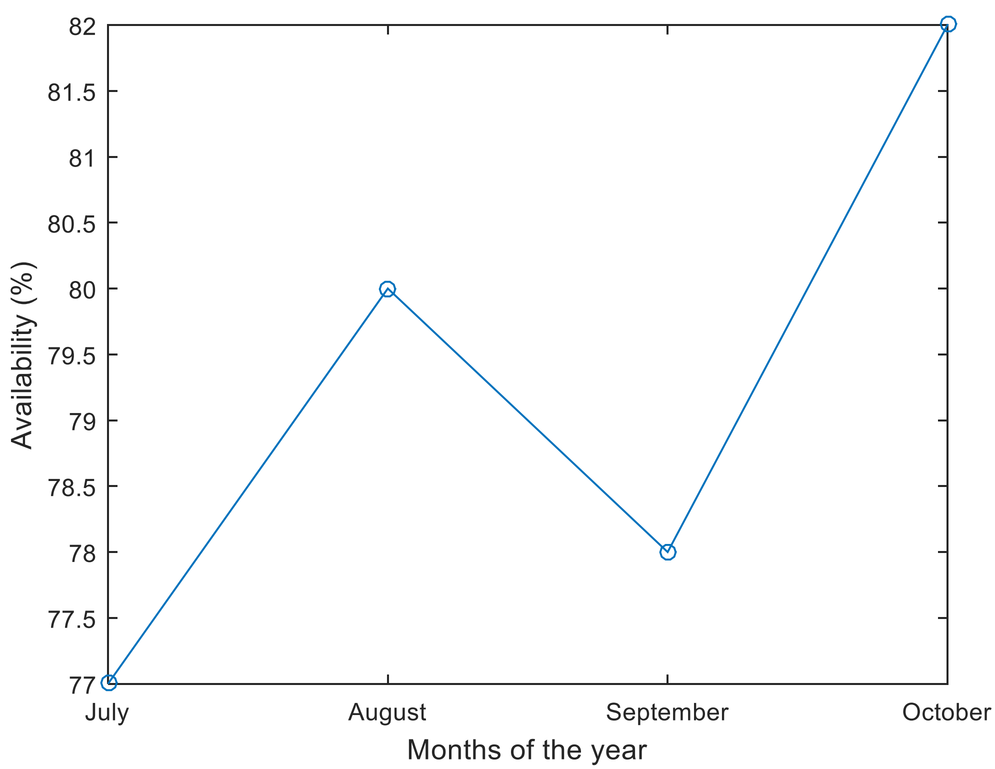


Figure 4: MTBF of Metcoppo machine for months of July to October. 2017



The plant availability that is a representation of the total operational functions of the metcoppo sheet production machine showed 77% for the month of July and 84% for the month of October respectively. The metcoppo machine availability is highest at 84% for the month of October, while the lowest were recorded for the month of August (80%) and September (80%). The value for the month of August and September were lowest due to schedule maintenance of the Metcoppo sheet production machine. The average plant availability is 80.25%. One may be right to conclude from the graph, that the Metcoppo Sheet Production machine is highly available.

Conclusion

From the research and findings revealed, the following conclusions were found:

a. The requirement for maintenance can be decided on the premise of the machines condition and the pattern of failures.
b. Failure of the metcoppo sheet production line seems to have reduced the company's production output.
c. The average plant availability is 80.25% which conforms to international standards.
d. Machine contamination, lubrication oil and other components like gear box failure, bearing, control panel of the production line were also seen as causes of the steptiles metcoppo production line.
e. It is revealed from findings that the machines operational conditions could have great effect on its reliability which could also affect the quantity of the needed spare parts for a given operational condition (Barabadi et al., 2011).

Recommendations

From the evaluation and results obtained, it is therefore recommended that:

a. Machine operators should be trained by experts on the use of industrial machines that will benefits the company by boosting its staffing level optimally.
b. Given the availability of requisite data, this research could equally be carried out on other machinery other than metcoppo sheet production line.

c. The safety of employees in the workplace should be considered in future research.

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APPENDICES

APPENDIX A: TOTAL OPERATING HOURS FOR METCOPPO SHEET MACHINE

Table 3.24: Total Operating Hours for the Month of July, 2024.

Date	Start Time	Stop Time	Easy Starts	Hours Run Per Day	Failure
01/7/24					
02/7/24					
03/7/24	9:40	15:00		4.20	
04/7/24	9:00			7.00	
05/7/24	8:00			8.00	
06/7/24	8:00			8.00	
07/7/24	9:00			7.00	
08/7/24					
09/7/24					
10/7/24	8:52	14:20		6.08	1
11/7/24	9:55			6.05	
12/7/24	8:00	14:20		7.20	
13/7/24	10:00	12:00		6.00	1
14/7/24	9:40	15:00		3.20	1
15/7/24					
16/7/24					
17/7/24	9:00	15:45		5.45	
18/7/24	8:00			8.00	
19/7/24	10: 10			5.50	
20/7/24	10:40	16:00		4.20	1
21/7/24	10:00			6.00	
22/7/24					
23/7/24					
24/7/24	8:00			8.00	
25/7/24	8:00			8.00	
26/7/24	8:00	13:30		6.00	
27/7/24	10:40	15:00		4.20	1
28/7/24	8:05	12:00		7.55	
29/7/24					
30/7/24					
31/7/24	8:55	15:55		4. 10	1
Total				**129.73**	**6**

Source: field survey.

Table 3.25: Total Operating Hours for the Month of August, 2024.

Date	Start Time	Stop Time	Easy Starts	Hours Run Per Day	Failure
02/8/24	8:00	12:00		8.00	
03/8/24	9:10			6.50	
04/8/24	8:30			7.30	
05/8/24					
06/8/24					
07/8/24	8:00			8.00	
08/8/24	8:00			8.00	
09/8/24	9:50		1	6.10	
10/8/24	10:00	15:25		5.35	1
11/8/24	9:00			7.00	
12/8/24					
13/8/24					
14/8/24	11:00			5.00	
15/8/24	8:00			8.00	
16/8/24	8:00		1	8.00	
17/8/24	10:40	14:00	1	4.20	1
18/8/24	10:20			5.40	
19/8/24					
20/8/24					
21/8/24	8:00			8.00	
22/8/24	8:00			8.00	
23/8/24	8:00			8.00	
24/8/24	9:40	14:00	1	5.20	1
25/8/24	11:30			4.30	
26/8/24					
27/8/24					
28/8/24	8:46			7. 14	
29/8/24	9:00		0	7.00	1
30/8/24	10:50	12:00	1	3.10	
31/8/24	8:30			6.00	
Total			**5**	**150.79**	**4**

Source: field survey.

Table 3.26: Total Operating Hours for the Month of September, 2024.

Date	Start Time	Stop Time	Easy Starts	Hours Run Per Day	Failure
01/9/24	8:40	12:00	1	6.20	
02/9/24					
03/9/24					
04/9/24	8:00			8.00	
05/9/24	8:44			7. 16	
06/9/24	9:00			7.00	
07/9/24	8:00			8.00	
08/9/24	8:55			7.05	
09/9/24					
10/9/24					
11/9/24	9:55			6.05	
12/9/24	8:00	14:20		7.20	
13/9/24	10:00	16:00		5.00	1
14/9/24	9:45			6.15	
15/9/24	9:00	15:30		6.30	1
16/9/24					
17/9/24					
18/9/24	8:00			8.00	
19/9/24	11: 10			4.50	1
20/9/24	10:48	13:50	1	5.02	1
21/9/24	10:20			5.40	
22/9/24	8:00			8.00	
23/9/24					
24/9/24					
25/9/24	8:00			8.00	
26/9/24	8:00	14:30		6.00	
27/9/24	9:50	15:55	1	3.05	1
28/9/24	11:45			4. 15	1
29/9/24	8:00	12:00		8.00	
30/9/24					
Total			**2**	**134.23**	**6**

Source: field survey.

Table 3.27: Total Operating Hours for the Month of October, 2024.

Date	Start Time	Stop Time	Easy Starts	Hours Run Per Day	Failure
01/10/24					
02/10/24	9:00	12:00		7.00	
03/10/24	8:55			7.05	
04/10/24	8:00			8.00	
05/10/24	10:50	15:30		4.10	1
06/10/24	9:00			7.00	
07/10/24					
08/10/24					
09/10/24	9:50		1	6. 10	
10/10/24	8:00			8.00	
11/10/24	8:50			7. 10	
12/10/24	8:00	12:00		8.00	
13/10/24	10:00	15:00		5.00	1
14/10/24					
15/10/24					
16/61/24	8:00		1	8.00	
17/10/24	9:40			6.20	
18/10/24	9:00	12:30		6.30	
19/10/24	11: 10			4.50	
20/10/24	10:42	13:50		5.18	1
21/10/24					
22/10/24					
23/10/24	8:00			8.00	
24/10/24	10:20			5.40	
25/10/24	8:00			8.00	
26/10/24	8:00	14:30		6.00	
27/10/24	9:45			5.15	
28/10/24					
29/10/24					
30/10/24	9:00	15:00	1	5.00	
31/10/24	11:35			4.25	1
Total			**3**	**147.33**	**4**

Source: field survey.

APPENDIX B: ANALYTICAL MODEL FOR THE METCOPPO SHEET MACHINE

$$MTBF = \frac{Total\ operating\ hours\ of\ the\ machine}{Total\ number\ of\ failures} \quad (3.55)$$

$$\lambda = \frac{1}{MTBF} \quad (3.56)$$

$$MTTR = \frac{Total\ outage\ time}{Total\ number\ of\ failures} \quad (3.57)$$

$$Machine\ availability = \frac{MTBF}{MTBF + MTTR} \quad (3.58)$$

Machine reliability $R(t) = e^{-\lambda t}$ (3.59)

$$Machine\ Quality\ (MC\ QTY) = \frac{Good\ sheets\ Produced}{Overall\ Sheets\ Produced} \quad (3.60)$$

APPENDIX C: MATLAB CODES: FOR MECOPPO MACHINE (MC1) PRODUCTION LINE

```
y=[21.62, 37.69, 22.37, 36.8];
figure, plot(y, '-*')
set(gca,'xtick',1:4,...
'xticklabel',{'July', 'August', 'September', 'October'})
xlabel('Months of the year')
ylabel('Mean time before failure (hrs)')
title('Mean time before failure vs. months of the year')
holdon
y1=[6.37, 8.3, 5.62, 7.2];
figure, plot(y1, '-d')
set(gca,'xtick',1:4,...
'xticklabel',{'July', 'August', 'September', 'October'})
xlabel('Months of the year')
ylabel('MTTR (hrs)')
holdon
y1=[77, 80, 78, 82];
figure, plot(y1, '-o')
set(gca,'xtick',1:4,...
'xticklabel',{'July', 'August', 'September', 'October'})
xlabel('Months of the year')
ylabel('Availability (%)')
```