Article

A Reliability-Centered Maintenance study for an Individual Section Forming Machine

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Abstract: This study investigated the breakdown trend in an automated production with an aim to recommend the application of Reliability-centered maintenance (RCM) for an improved productivity via a new preventive maintenance (PM) program. Individual Section-forming machine (ISM): a glass blowing machine for making glass bottles was used as the case study of an automated production system. The machine parts and the working mechanisms were analysed with a special focus on methods of processes and procedures that will enable the ISM maintenance department run more effective and achieve its essential goal of ensuring effective machine operation and reducing machine downtime. In this work, information is provided on the steps and procedures to identify critical components of the ISM using Failure Modes and Effect Analysis (FMEA) as a tool to develop an optimal maintenance program based on the reliability data of the equipment's functional components. A relationship was established between the failure rate of the machine components and the maintenance costs such that using the recommended PM program, an evidence of improvement in the machine's availability, safety and cost-effectiveness will result into an increase in the company's profit margin.

Keywords: Reliability Centered Maintenance (RCM), Individual Sectioned forming Machine, FMEA, Risk Analysis

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1. Introduction

The high level of competition among the industries and businesses has made the survival battle to be tremendously strong. All over the world, development times are becoming shorter, cost concerns more severe, and customers are demanding absolute safety and high reliability of products. This quest also includes the employees who always desire a safe environment to perform their task. While it may have been sufficient in the past to focus on testing and analysis as the primary methods for ensuring high reliability, this is no longer obtainable. The focus is on anticipating the factors that lead to failure and ensure that such factor is prevented from occurring frequently using a robust design. To reach this goal, decrease in the costs of operations are set on the high priority [1]. The study of reliability and maintainability in any manufacturing outfit plays a crucial role in ensuring the smooth running of production processes because it could be useful in ensuring production continuity as well as product quality assurance [2].

Nowadays there is much emphasis on safety, reliability and availability in the production plants. In an attempt to beef up performance an increasing number of industries replaces the reactive maintenance strategies with proactive strategies like predictive and preventive maintenance (PPM) as well as aggressive strategies such as Total Productive Maintenance (TPM) [3]. Maintenance has been referred to as a single largest controllable cost which can be used to improve productivity through attempts on different maintenance policies [4].

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Peer-reviewed version available at Machines 2018, 6, 50; doi:10.3390/machines6040050

Lately, the decision-making tool that has been widely implemented is Reliability Centered Maintenance (RCM). RCM is used to determine what failure management strategy(ies) can best be deployed to ensure that a system achieves a desired level(s) of operational reliability, safety and readiness and then environmental safety in the most economical manner [5]. RCM is a systematic consideration of system functions, failure analysis and a priority-based consideration of both safety and cost-effectiveness. It is a process used to determine what must be done to ensure that any physical asset continues to fulfill its intended functions in its present operating context. [6]. Over these 30 years of initiating RCM it has been tested and confirmed to be an effective preventive maintenance (PM) optimization strategy, a method that has enjoyed increasing popularity in a wide range of different industrial set ups [7]. PM's objective is usually to crash the probability of having a non-scheduled maintenance, which typically comes high costs. Bolu C.A (2013) established the relationship between the measurement of maintenance performance and productivity as the major determinants of maintenance costs by adopting the following equations:

$$Cost\ of\ Maintenance = \frac{\text{Total Maintenance Cost}}{Total\ Maintenance\ Hour}$$

and

$$Maintenance\ Cost\ Component = \frac{\text{Total Maintenance Cost}}{Production\ Output}$$

therefore

$$Cost\ Reduction\ Ratio = \frac{Routine\ Service\ Workload}{Cost\ of\ Maintenance\ Hour}$$

Given

$$Routine\ Service\ Workload = \frac{Planned\ Maintenance\ Hour}{Total\ Maintenance\ Hour}$$

Implying that the overall objective of the maintenance function is to support the production department by keeping facilities in proper running condition at the lowest possible cost [8]. Like for many other machines, RCM has been a successful PM strategy, this time it is being tailored for use in an ISM to aid the design of a planned component replacement (PCR) schedule [9]. The aim of this research is to examine the present maintenance culture of an ISM in a glass bottle moulding industry and to establish an RCM plan on this machine. From this, the PM intervals that give the best performance values was identified for an optimum maintenance plan and reduction in service period and frequency.

1.1. Brief Description of Individual Section Machine (ISM)

The Individual Section machine (ISM) is an automatic machine used in producing hollow glass containers having narrow or wide necks. The machine is designed to be extremely flexible, hence it is very efficient for the production of a very large range of containers depending on the mould installed. system. A furnace is usually an integral part of an ISM which heats up the temperature to over 1400°C to melt the glass. The molten glass passes through a foreheart to the feeder where it is being cut into uniform gobs of glass i.e the liquid glass drops by a thermal shearing and distribution system. After this, the gobs are being sent to an ISM where the temperature goes down below 1200°C, and the gobs are injected into the molds. The ISM molds are in two sets - "the blank" and "the blow" [10]. The forming section is pneumatically driven, whereas the Feeder mechanism, the gobs distributor and the pushers can be controlled by servo control or stepping motors. A solenoid-pneumatic valve block controlled by an electronic timer controls the mechanisms in all sections automatically [11]. Owing to the servo-controlled gob distributor, the number of machine sections to

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be used and the feeding sequence can be programmed without operating the mechanism: programming through the machine terminal is the only operation needed. The electronic pushers transfer the items from the cooling plate to the conveyor accurately, thus improving item alignment on the conveyor; time needed for job changes is therefore reduced as the pushers can be completely programmed. There is no need to stop the machine to adjust all operations [12]. Independent sections can be available so that adjustment and repair operations, as well as the replacement of moulds in each individual section, can be performed without stopping the other sections. The ISM is a critical success factor in glass bottle production and it is more rewarding if kept at the optimum in-service condition.

Figure 1: Typical individual section forming machine (ISM). [12]

1.2 Overview and review of RCM related work

Like many other maintenance planning tools, RCM is to preserve an item's functionality. RCM seeks to curtail the criticality of failure as all failures can never be eradicated. The first priority of RCM is safety in cases where safety is not jeopardised, the priority becomes maintenance; justified by the ability to complete the mission of availability and reliability and then the final priority is based on cost-effectiveness [13]. These cumulating into making use of RCM for the design of the system; system's operation modes; the maintenance methods and practices; logistics and costs data (analysis) to improve operating capability of such system(s). RCM should be a continuous process that requires sustainment knowing fully well that at any system's best, maintenance can only sustain a system to its inherent reliability and availability level within the operating context [14]. The condition-monitoring system (CMS) is an integral component of RCM in order to increase productivity and reliability of machines as shown in the figure 2 below (Item 3). The conditions leading to a failure mode must have been or be investigated using sensors like Accelerometers, Encoders, Current/torque sensors, Pressure sensors as well as temperature sensors [15].

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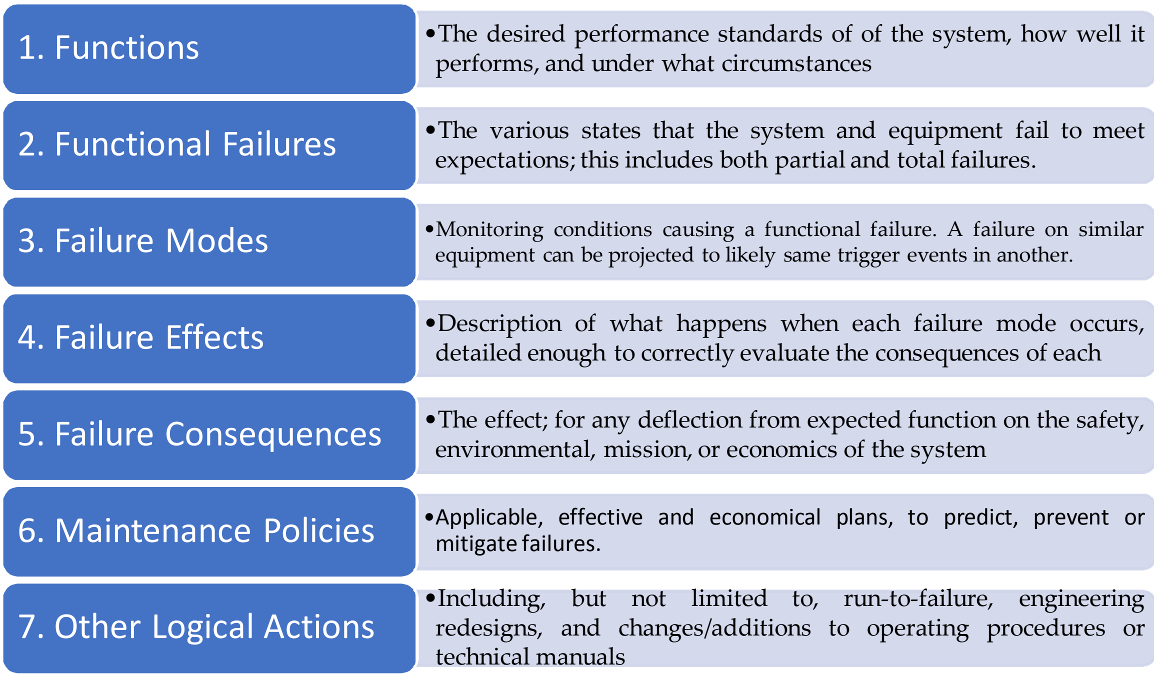

Figure 2: An overview of the items of RCM process in sequence [16]

From the past researches it is evident that RCM have been used as a tool to sort out of failure problems ranging from field of medicine to military to building related technologies to Automotive to Aviation and of course Industrial and productions to mention few, however, a lot of applied areas are yet to be investigated or reported. Wang et al (2000) carried out an RCM Analysis of Process Equipment using Heat exchangers as a case study. Results indicated that RCM could assist in identifying the functional failures, causes of failures and risk ranking which are linked to corrosion rates and remaining life of the heat exchangers. Afefy (2010) investigated the application of RCM methodology to the development of a maintenance plan for a steam-process plant. The proposed RCM spiced PM planning indicated that the system will enjoy about 25.8% decrease of the total labour cost, 80% reduction of the total downtime cost and also about 22.17% decrease in the annual spare parts cost for a year of the proposed RCM-PM planning application. Ramli & Arffin (2012) carried out research on RCM in Schedule Improvement of Automotive Assembly Industry. The number of the checklist in the body shop was reduced and this resulted in a significant reduction of operator's workload and avoided maintenance personnel from committing fraud. It was confirmed that the implementation of RCM gave great success and the same methodology can be applied to the whole equipment in the other shops [17], [18], [19].

Tarar (2014) carry out a study on Reliability Centered Maintenance (RCM) of Rotating Equipment through Predictive Maintenance. This paper evaluated the effectiveness of existing maintenance strategy with improvement proposals. It showed RCM process and a case study of paint booth fans process. The paper revealed that the successful RCM implementation in any industry can ensure better performance to take competitive advantage in the global market. Recently, Emovon Et al (2017) carried out a review on the development of more effective RCM tools for maintenance practices in plant systems for an increased safety and efficiency. The authors expressed concern about the use of the risk priority number (RPN) as they established the fact that it does not address certain important factors such as economic cost and environmental impact in the risk analysis. Consequently, Emovon and Okwu (2018) integrated Weighted Aggregated Product Assessment (WASPAS) into

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RCM as an alternative for prioritizing using RPN. The technique improves the effectiveness of RCM as well as in selection of an optimal maintenance strategy for ship facilities. Further to the previous researches that have been carried out, this research seeks to implement the RCM for Individual section machine (ISM) which is used in glass bottle Production Company. However, RPN is considered the best for the form of data collected for this study as some of the alternatives that have been used are found to require a maintenance data collection pattern a little different from the conventional [20], [21].

2. Materials and Methods

2.1 Components of Individual Section Machine (ISM)

The Individual Section machine is composed of even-numbered sections. Besides operating as a single machine, two machines can be connected in line. Furthermore, the number of working sections can be changed when the kiln delivery capacity is of fundamental importance. To produce special items, auxiliary mechanisms and equipment are available to be used on the machine such as the Single, Double, Triple, Quadruple Gob, Blow-blow, Press-Blow, Narrow Neck Press-Blow processes, vacuum mould and blow mould support, as well as special equipment for the different production processes. A more flexible production system is at present available owing to the Servo-Feeder, Gob Servo-Distributor, Servo-Pusher and the electric shaft system for flexible lines.

2.2 Mechanism Selection Process

The criteria for the selection of the components are as follows;

- The frequency of downtime/failure of a component.
- Type of components as to whether it is a mechanism or a variable.
- Criticality of component failure.
- Availability of technical description and maintenance guidelines for component.
- Information gathered from a questionnaire on the reliability of components.

2.3 Questionnaire Design for Individual Section Machine Maintenance Staff

In the course of the research, questionnaires were administered to all maintenance staff, key production crews and forehearth staff of Beta glass Plc. The Company is located at Ogun State in Nigeria. They are specialized in the production of glass containers particularly bottles. The aim of the questionnaires was to investigate the machine functionality, capability and reliability and also the distribution of roles in the maintenance department.

2.4 Failure Risk Analysis.

For each of the identified components of all parts of the ISM, the risk analysis of experiencing any form of failure was conducted based on the available data, using Failure Modes and Effect Analysis (FMEA) and also, a downtime analysis of the components across the period was considered.

Step 1: Review the process or product.

Step 2: Brainstorm potential failure modes.

Step 3: List potential effects of each failure mode.

Step 4: Assign a severity ranking for each effect.

Step 5: Assign an occurrence ranking for each failure mode.

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Step 6: Assign a detection ranking for each failure mode and/or effect.

Step 7: Calculate the Risk Priority Number for Each Failure Mode

The risk priority number (RPN) was simply calculated by multiplying the severity ranking times the occurrence ranking times the detection ranking for each item.

Risk Priority Number = Severity × Occurrence × Detection ………………(i)

The mechanism Input sources for FMEA is as follows:

- Questionnaires completed by maintenance staff,
- Downtime data showing details of failure which occurred,
- Working drawings of components,
- Maintenance instructions as provided by manufacturers,
- Failure modes and effects analysis of standard mechanical components,
- On field assembly and disassembly during repairs and diagnostics of fault.

2.5 Downtime Analysis

The downtime and the effective downtime for each quarter were collated for the following selected critical mechanism using the data retrieved from previous maintenance reports.

- Pusher cylinder
- Plunger mechanism
- Ware transfer

In calculating the effective downtime for each mechanism in each quarter the following formula was used:

$$D_e = D \cdot N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where: $D_e = effective\ down\ time$

$D = downtime\ recorded$

$N = number\ of\ sections\ affected$

With the values of the downtime for each mechanism in each quarter collated the financial loss as a result of downtime was obtained with the formula:

$$L_d = D_e \cdot V \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where: $L_d = loss\ due\ to\ down\ time$

$V = average\ production\ speed\ price$

$$V_p = V_b \cdot P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where: $V_p = average\ production\ speed\ price$

$V_b = bottle\ speed$

$P = unit\ price$

Also, the cost of downtime is estimated by taking note of the production speed for each product as shown in Table 1 below.

Table 1: Cost analysis of downtime

Product (Bottle)	Machine speed(bpm)	Unit price (Naira)	Bottle speed(bpm)	Production speed price (₦/m)
A	53	46.83	106	4963.98
B	89	29	178	5162
C	86	36.8	172	6329.6
D	63	48.47	126	6107.22

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E	110	44.5	220	9790
F	130	44.5	260	11570
G	80	39.74	160	6358.4
H	126	39.74	252	10014.48
I	98	26.4	196	5174.4
J	112	19.05	224	4267.2
K	92	26.4	184	4857.6
L	43	44.56	86	3832.16
M	76	38.26	152	5815.52
N	122	12.36	244	3015.84

$$V_b = V \cdot n \text{ ....4}$$

Where: $n = number\ of\ gob$

There were two gob mates in the plant hence, the machine produces two bottles per unit delivery time. During the analysis, all electrical and non-direct control related issues were not considered.

3. Results and Discussion

During the time of this project, FMEAs were developed and downtime analysis was done for the following selected critical components:

- Pusher cylinder
- Plunger mechanism
- Ware transfer

3.1 Discussion of Results for Pusher Cylinder

From the distribution in figure 3, assigned numbers (1-17) had the following causes ranked by RPN.

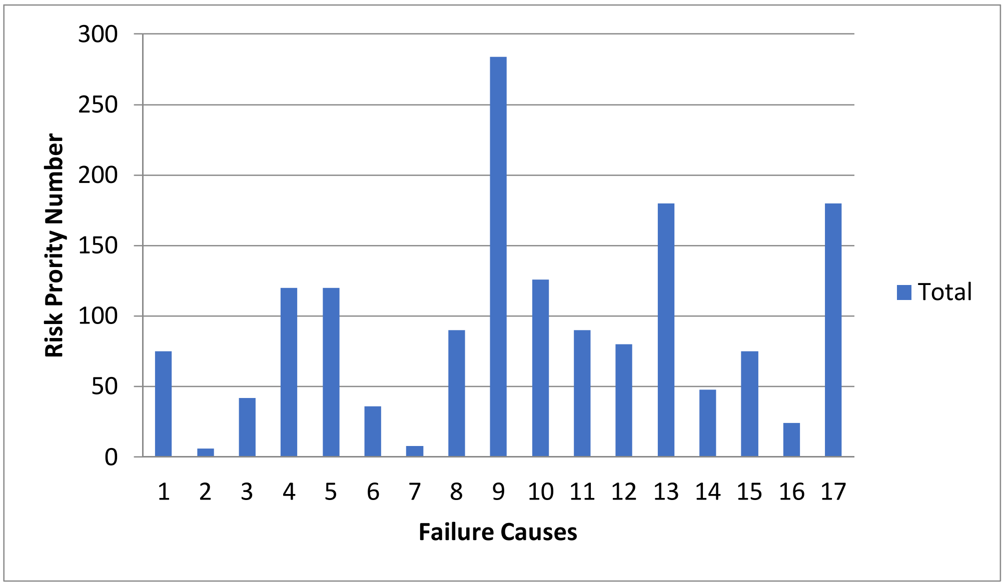

Figure 3: Distribution of failure causes to RPN for pusher Mechanism

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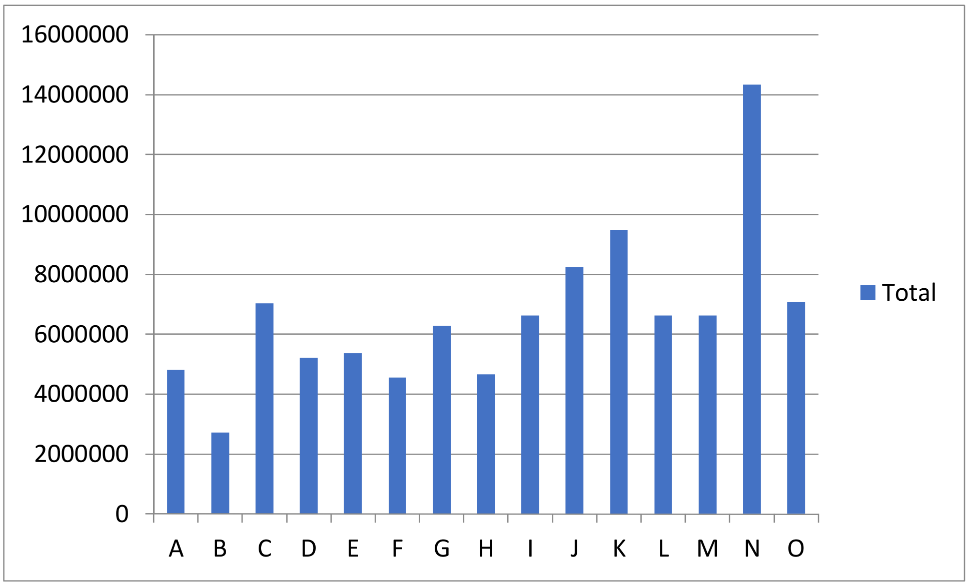

Figure 4: Loss in the cost of product not produced across quarterly periods.

It is observed that the highest RPN of 284 was due to cause 9 which is lubrication and wears out with potential failure mode of broken piston ring which causes internal leakage and inappropriate/slow response of the pusher cylinder arm out and in, also it can be seen that inappropriate tightening practice when it comes to bolted parts also account for majority of the failure mode as seen in cases of over tightening in cause 13 and excessive vibration in cause 17, this has the effect of bringing about work loosing of the assembled leading to inappropriate operation and also external leakages. Lesser RPN was observed for causes such as bad control and wear of pusher fingers due to high temperature and ash working environment these failures had very low occurrence rates and were very detectable in cases in which they occurred.

3.1.1 Downtime and Cost Analysis

Since a good maintenance culture involves continuous improvement in the reduction of product loss cost due to downtime a general improvement in the cost due to downtime was not observed across the 15 quarters in fact the highest downtime cost loss was experienced recently in the fourth quarter of 2013 with a total loss in cost of product not produced was calculated to be **₦14, 347,774.06**

3.2 Discussion of Results for Plunger Mechanism

From the distribution in fig 4, assigned numbers (1-11) had the following causes ranked by risk. It is observed that the highest RPN of 225 was due to cause which is the presence of Carbon residue in upper cylinder with potential failure mode of the plunger being stuck during operation due to the absence of clearance, also it can be seen that wear of the upper cylinder which is due to a failure mode of air leakage in piston assembly had an RPN of 196 followed by an RPN of 192 due to mismanagement of excessive working pressure which makes the plunger supply hose connector pull off. A generally high- RPN was observed for all failure causes which shows the severity of occurrence of such causes with causes due to gasket flat having the lowest RPN of 84 due to failure modes of air leakage in inner mould during parison this is because pressure losses due to leakage can be compensated for increasing the pressure and even in cases of incomplete parison blowing, the effect is self-corrected during the final blowing process.

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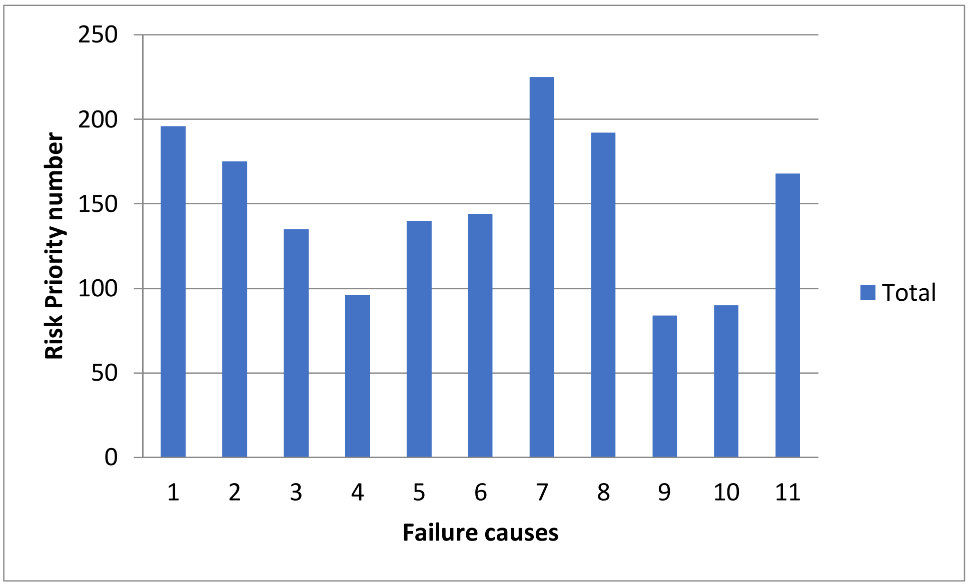

Figure 5: Distribution of failure causes to RPN for plunger mechanism

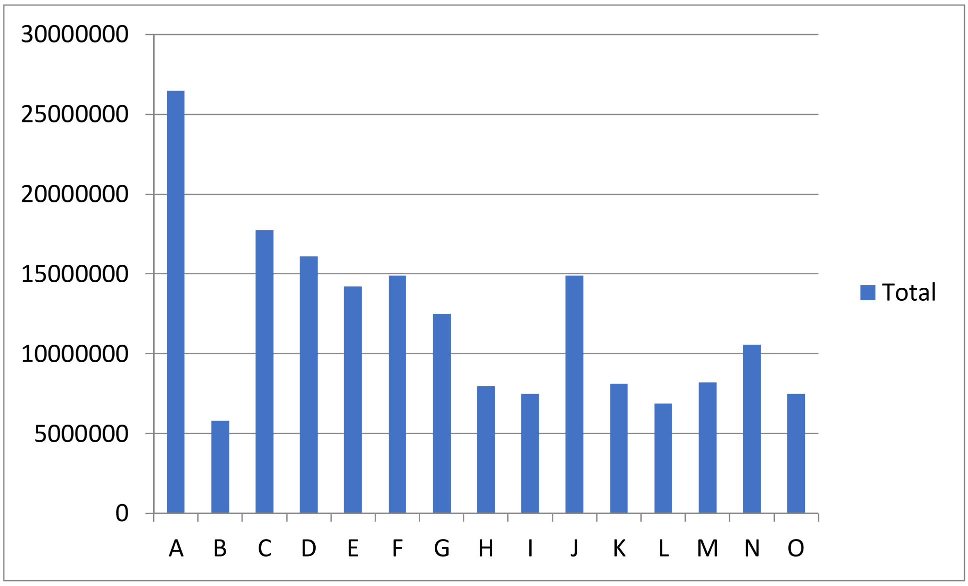

Figure 6: Loss in the cost of product not produced across quarterly periods for plunger mechanisms

3.2.1 Downtime /Cost Analysis:

Since a good maintenance culture involves continuous improvement in the reduction of product loss cost due to downtime a generally there was improvement in the reduction of cost loss in downtime due to product not produced and from Fig 6 it can be seen the first data representation i.e. third quarter of 2010 had a downtime cost of **N26,470,458.91** and generally the downtime cost due to product not produced decreased relatively steadily with the final downtime cost in the first quarter of 2014 being **N7,504,222.40.**

3.3 Discussion of Results for Ware transfer

From the distribution in fig 7, assigned numbers (1-13) had the following causes ranked by RPN.

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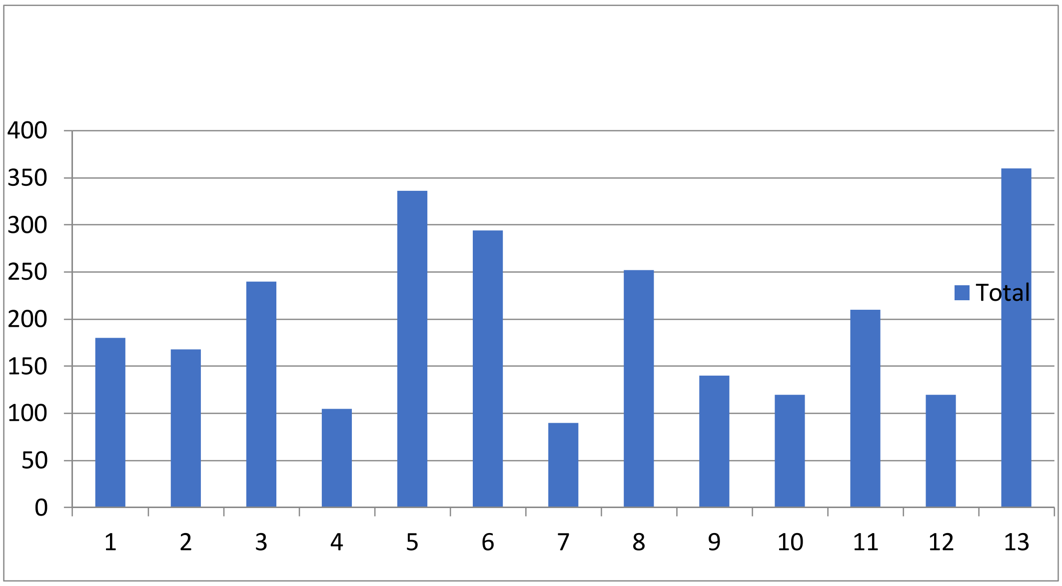

Figure 7: Distribution of failure causes to RPN for ware Transfer

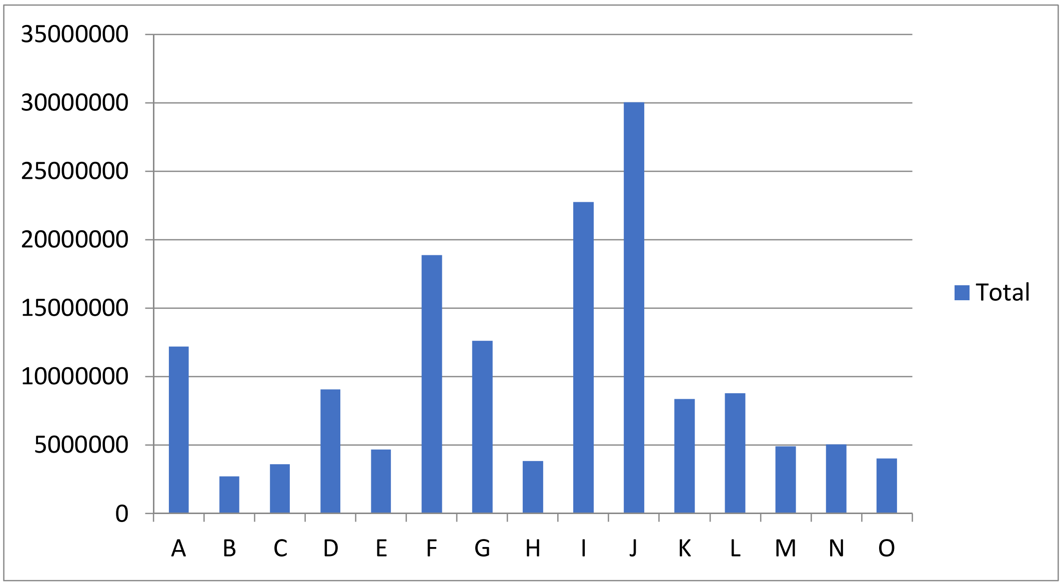

Figure 8: Loss in the cost of product not produced across quarterly periods for Ware Transfer

It is observed that the highest RPN of 360 was due to cause 13 which is excessive heat, contamination with potential failure mode of worn out wear transfer fingers, also a temperature related cause of high temperature due to excessive speed when there is deficiency in lubrication has a RPN of 336 and a failure mode of the wear transfer main bearing seizing another area of risk of the component was due to lubrication defects especially contaminants in the lubricant for the bevel gear lubrication sump this has failure mode of abrasive wear of the bevel gears used in transmission of motion for the shaft and has an RPN of 294.

Other lower cases of low- RPN is observed in the case of the loose bevel gear off on the shaft due to a shear on the key; this is because the chances of this happening is highly unlikely and the failure mode itself is very detection even in the early phase of installation and maintenance activity another cause with low-risk priority of 105 is what is popularly known is cullet hook, this has a relatively high occurrence rating of 7 but is very easily detected and quite easy to correct hence a low severity rating number.

3.3.1 Downtime /Cost Analysis:

Generally considering the broad spectrum of all the quarters considered using Fig. 8, most of the time there is quite low loss of production loss due to wear transfer failure except for extreme cost loss of over 30 million naira in the fourth quarter of 2012 and similar loss of **N 22,737,045.94** in the third quarter of 2012 despite this there has a relatively decreasing trend shown in the loss in cost due to downtime since the first quarter of 2013 with the lowest loss in cost due to downtime occurring in the first quarter of 2014 with a loss in cost due to downtime being **₦4,013,886.40**

4. Conclusions and Recommendation

4.1 Suggestion for the Improved reliability of Pusher Assembly

Implementation of the selective run to failure, preventive maintenance and precision maintenance respectively will lead to the lesser downtime cost and higher reliability of the pusher assembly. Through careful analysis of all the components of the pusher assembly, it was observed that most of the failure that occurs is due to random causes and over stress with the exception of all seals and piston rings. Use of precision Maintenance requires that all bolts on the assembly should be locked with equal and right torque as shown in the torque chart provided; also avoiding the reuse of bolts will help reduce failure due to work loose and bolt breakage (shear); the use of adhesives in place of bolts and nuts is recommended here. A redesigning of the pusher finger support is suggested on the basis of material selection since its excessive expansion causes the pusher finger bolts to work loose and misalign. The Oilers on all pusher assembly must be reinstalled and frequent cleaning of both the Oilers and the cylinder shaft be carried to avoid accumulation of carbon and dirt which blocks the oilers and makes the cylinder shaft stuck.

4.2 Failure Reporting and Analysis Recommendation

All recorded downtime on individual sections should not be divided by the total number of sections on the particular machine. Dividing the downtime recorded by the number of section assumes that the other sections due to the fact a particular section down compensates for the failed section by producing more but since this is not so the KPI (key performance Indicator) of each machine line should be calculated individually. There is the need for better failure reporting discipline to be imbibed in the department, this, however, involves input from workshop floor for failure causes that are not be determined on the machine this will help in filling more accurately the FMEA table and carrying out a more detailed failure analysis.

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