Industrial Engineering Letters www.iiste.org
ISSN 2224-6096 (Paper) ISSN 2225-0581 (online)
Vol.3, No.1, 2013

Identification and Solution of Maintenance Challenges in a Production Line

Remy Uche
Department of Mechanical Engineering
Federal University of Technology, Owerri, Nigeria
ucheremy@yahoo.com

Ekelechi Ogbonnaya
Shell Development Company of Nigeria
Port Harcourt, Nigeria.

Abstract
This work attempts to identify the root causes of machine and equipment breakdowns in a production line. The evil effects of machine shutdown on manufacturing targets in volume and deadlines are comprehensively highlighted. The relevant data were obtained in a field survey of three reputable production companies in a given business and budget year. The result shows that the major maintenance challenges in a typical production line are poor spare parts inventory management, lack of technical competence of production and maintenance operatives, ageing machines and equipment, inadequate maintenance budget, and poor leadership of the firm's management team. The work suggested robust technical solutions as remedies which include aadequate consideration of maintenance during the projection initiation phase, application of N+1 philosophy, strategic inventory control, adoption of computerized maintenance management system (CMMS), adherence to condition based maintenance or predictive maintenance, aaggressive pursuit of total productive maintenance (TPM), and staff competence development and motivation.
Key words: Machine-breakdown, Production, Manufacturing, Condition-monitoring, preventive-maintenance, predictive-maintenance, total-productive-maintenance.

1.0 INTRODUCTION

Machine and equipment breakdowns found in most manufacturing industries in developing countries like Nigeria and the adverse effects on the overall performance of the organisation ranging from production loss, high production cost, obvious inability to meet production deadlines, poor company's reputation and loss of integrity which invariably reduces the share capital and the ability to compete with similar industries creates a window of research for possible remedies. The major emphasis of this work will be the development of workable strategies which will drastically reduce or totally eliminate machine and equipment breakdowns in a production line. This strategy will project maintenance as:

- Activities carried out to achieve asset availability, reliability and integrity at a minimal and acceptable cost.
- Strategies that enhance long term plant viability.
- Business programs that ensure profitability by providing availability of the plant at optimal maintenance cost.

This approach helped maintenance practitioners to justify that maintenance cost is an investment towards plant viability and profitability [1].

2.0 BROAD VIEW OF MAINTENANCE

Maintenance may be defined as actions necessary for retaining or restoring a piece of equipment, machine, or system to the specified operable condition to achieve its maximum useful life [2]. Also, maintenance can be look as "all actions which have the objective of retaining or restoring an item in or to a state in which it can perform its required function". The actions include the combination of all technical and corresponding administrative, managerial, and supervisory actions.
The primary objective of maintenance is to ensure that physical assets continue to fulfill their intended functions throughout the lifetime of the assets [3]. However, if asset is not maintained the effects are; high equipment downtime, production losses and deferment, high product unit cost, poor quality control etc [4].

Considering the importance of maintenance to the business, the following improvement steps are advocated:

- Improvement of equipment reliability and availability
- Selection of cost effective and appropriate preventive maintenance (PM) tasks and techniques
- Optimization of maintenance efforts and cost.
- A shift from a reactive to a proactive maintenance regime.
- Fulfillment of all expectations from all stakeholders without jeopardizing safety and technical integrity.

2.1 TYPES OF MAINTENANCE:

Generally speaking, there are two types of maintenance in use:

- **Corrective Maintenance**: Corrective maintenance can be defined as the maintenance which is required when an item has failed or worn out, to bring it back to working order [5]. It is carried out after fault recognition and intended to put an item into a state in which it can perform a required function. This maintenance is often most expensive because worn equipment can damage other parts and cause multiple damage. Corrective maintenance is probably the most commonly used approach, but it is easy to see its limitations. When equipment fails, it often leads to downtime in production. In most cases this tends to be costly to the business. Also, if the equipment needs to be replaced, the cost of replacing it alone can be substantial. Corrective maintenance is carried out on all items where the consequences of failure or wearing out are not significant and the cost of this maintenance is not greater than preventive maintenance. This type of maintenance can be regarded as unplanned, emergency, breakdown maintenance.

- **Preventive Maintenance:** This is the care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing for systematic inspection, detection and correction of incipient failures either before they occur or before they develop into major defects [6]. This type of maintenance has many different variations and is subject to various researches to determine the best and most efficient way to maintain equipment. Recent studies have shown that Preventive maintenance is effective in preventing age related failures of the equipment. For random failure patterns which amount to 80% of the failure patterns, condition monitoring proves to be effective [7]. So to avoid the problems of correcting unfortunate situations that have already arisen, many try to maintain equipment before it fails. By doing this, the goal is to avoid failure, unnecessary production loss and safety violation. This type of maintenance can as well be regarded as Planned, Predictive, Condition based, Running, Opportunity and Reliability Centred maintenance.

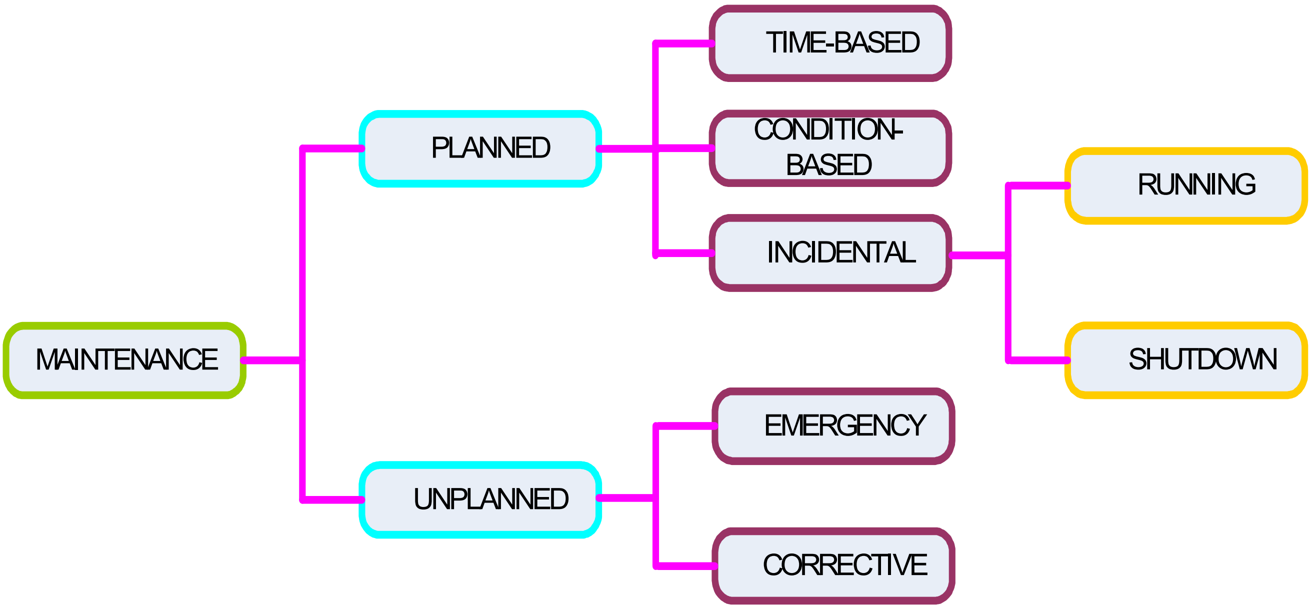

Figure 1.0 Types of maintenance can be summarised with the below chart.

2.2 EVOLUTION OF MAINTENANCE

The first generation of maintenance started about 1940 till 1950 [8]. It is characterised by reactive mode which is mostly fixing equipment any time it fails (breakdown/corrective maintenance). The asset availability and reliability is not guaranteed and production losses and deferment are always encountered. Within this period, industry was not fully mechanised, so downtime did not matter much. This implies that prevention of equipment failure was not a priority. At the same time, most equipment was simple in design and can be easily repaired. Maintenance operations were simply cleaning, servicing and lubrication routines [9].

Second generation of maintenance (1950 – 1977) improved on the first generation, where the focus is on preventive maintenance rather than corrective. The Second World War changed so many things. The wartime pressures increased the demand for goods of all kinds while the supply of industrial manpower dropped sharply. This gave rise to increase in mechanization. Machines ranging from simple to complex ones were produced. Industries now depend on them to meet up targets in volume and quality. As this dependence grew, downtime came into sharper focus. The danger of not meeting production deadlines due to machine failure/downtime became a source of worry. This situation gave rise to the concept of preventive maintenance. The objective is to forestall any situation that can generate machine/equipment downtime in a production system. The cost of maintenance started to rise relative to the other operating costs. This led to the growth of maintenance planning and control systems. These have helped to bring maintenance under control, and are now an established part of the practice of maintenance. The expectations of maintenance in the second generation of maintenance include higher equipment availability, longer equipment life and lower maintenance cost.

The third generation of maintenance commenced from 1978 – 2000. Since the mid-seventies, the process of change in the industry has gathered greater momentum. Equipment/machine failures and their inherent consequence of downtime are not tolerable. Downtime has always affected the productive capability of physical assets by reducing output, increasing operating costs and interfering with customer service. Therefore, the third generation of maintenance centres on predictive maintenance which have the following objectives:

- Higher plant availability and reliability.
- Greater safety.
- Better product quality
- No damage to the environment
- Longer equipment life
- Greater cost effectiveness

The fourth generation of maintenance [2000 till date] has a thrust in preventive maintenance. The whole essence of this concept is to improve plant availability and reliability at optimum cost as summarized below.

- Maximising production or increasing facilities availability at the lowest cost and at the highest quality and safety standards.
- To ensure effective system optimization, eliminate equipment downtime and production deferment.
- Maintain high equipment availability and reliability, improving equipment efficiency and reducing scrap rate.
- Minimising energy usage and optimising the useful life of equipment.
- To optimise maintenance resource cost within the constraints of safety and plant condition standards.
- Improving spares stock control
- Product unit cost reduction and profit maximization
- Providing reliable cost and budgetary control
- Identifying and implementing cost reductions

3.0 EQUIPMENT AVAILABILITY AND RELIABILITY

3.1 Equipment Availability is the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or during a given time interval, assuming that the required external resources are provided [10].

Availability can be calculated as: {total time – (planned + unplanned downtime)}/ total time.

Equipment Availability {A}, in the simplest form, is:

Uptime / (Uptime + Downtime).

Inherent availability looks at availability from a design perspective:

A_i = MTBF/ (MTBF+MTTR)

MTBF = Uptime / Number of System Failures
MTTR = CM Downtime / Number of System Failures

If Mean Time Between Failure (MTBF) or Mean Time To Failure (MTTF) is very large compared to the Mean Time To Repair (MTTR) or Mean Time To Replace (MTTR), then you will see high availability. Likewise if mean time to repair or replace is miniscule, then availability will as well be high. As reliability decreases, MTTF becomes smaller and of better maintainability i.e. shorter MTTR will be strongly needed to achieve the same availability
Redundancy is equally used to achieve high availability by including enough excess capacity in the design to accommodate a performance decline. The simplest example is a boat with two separate engines driving two separate propellers. The boat continues toward its destination despite failure of a single engine or propeller. A more complex example is multiple redundant power generation facilities within a large system involving electric power transmission. Malfunction of single components is not considered to be a failure unless the resulting performance decline exceeds the specification limits for the entire system.

3.2 Equipment Reliability is the probability that an asset will perform its intended function for a specified period of time under specified operating conditions.
Actual Reliability is a function of the asset's design, manufacturing process, usage profile, operating environment, and maintenance program.

Reliability in the simplest form is described by the exponential distribution (Lusser's equation), which describes random failures:

$$R = e^{\wedge} [-(\lambda * t)] = e^{\wedge} [-(t/\Theta)] = e^{\wedge} (-N)$$

Where t = mission time (1 day, 1 week, 1 month, 1 year, etc which you must determine). λ = failure rate, $\Theta = 1/\lambda$ = mean time to failure or mean time between failures, and N = number of failures during the mission—note the number of failures during a mission can be a fractional value. Notice that reliability must have dimension of mission time for calculating the results
When the MTTF or MTBF or MTBM is long compared to the mission time, you will see reliability (i.e., few chances for failure). When the MTTF or MTBF or MTBM is short compared to the mission time, you will see unreliability (i.e., many chances for failure).
Equipment availability is driven by time lost while Reliability is driven by number of equipment failures. How much reliability and availability one needs depends upon available resources. Tradeoffs must be made to find the right combinations for the lowest long-term cost of ownership, which is a life cycle cost consideration

4.0 DATA ACQUISITION

The thrust of the research data are both primary and secondary in nature. The primary sources of data were obtained from three production based industries. These industries are very functional and reputable. They are – Company A [Nigerian Breweries PLC.], Company B [Star Paper Mills Ltd.], and Company C [Shell Petroleum Development Company Ltd [SPDC]]. The relevant data were gathered through physical interactions with the Operations and Maintenance Team in the specified industries in one part and personal observations on the other part. The data were classified into - maintenance strategies deployed by respective companies, rate of equipment breakdown and failure analysis, maintenance cost and trend, maintenance challenges and improvements. The secondary sources of data include newspapers and newsletters, published findings, journals, corporate maintenance and integrity department of Company C, TPM department of Company A., and maintenance department of Company B and surfing the internet.
The maintenance records of the three companies within a given budget year was critically examined. The results are thus presented:

5.0 RESULTS AND DISCUSSIONS

5.1 Company A

Maintenance policy and maintenance strategy drive the operations in Company A. These are stated as follows:

(a) **Maintenance Policy**: "To implement and sustain efficient & effective Planned Maintenance at minimum cost and ensure that physical assets continue to fulfill their intended functions throughout the lifetime of the assets"
(b) **Maintenance Strategy**: The strategy was adopted based on the consequence of equipment failure, the nature of products the machines are handling and Original Equipment Manufacturer (OEM) recommendations on respective equipment. This strategy can be referred as **maintenance plan which can be either calendar or time based. The maintenance plans adopted in the company are mostly calendar based**, that is (one/three/six monthly inspections of D-3412 generator, Boiler, Washing machine etc).

Figure 2.0 below, is a bar chart that shows maintenance activities (Work Order Execution Rate to date – Oct / Nov.2009) carried out in Company A, which indicates a total planned work orders, completed work orders and percentage of completion across different sections of the industry. A planned work order could be preventive or corrective maintenance, but in this case, it is corrective maintenance that is presented in the bar chart below.

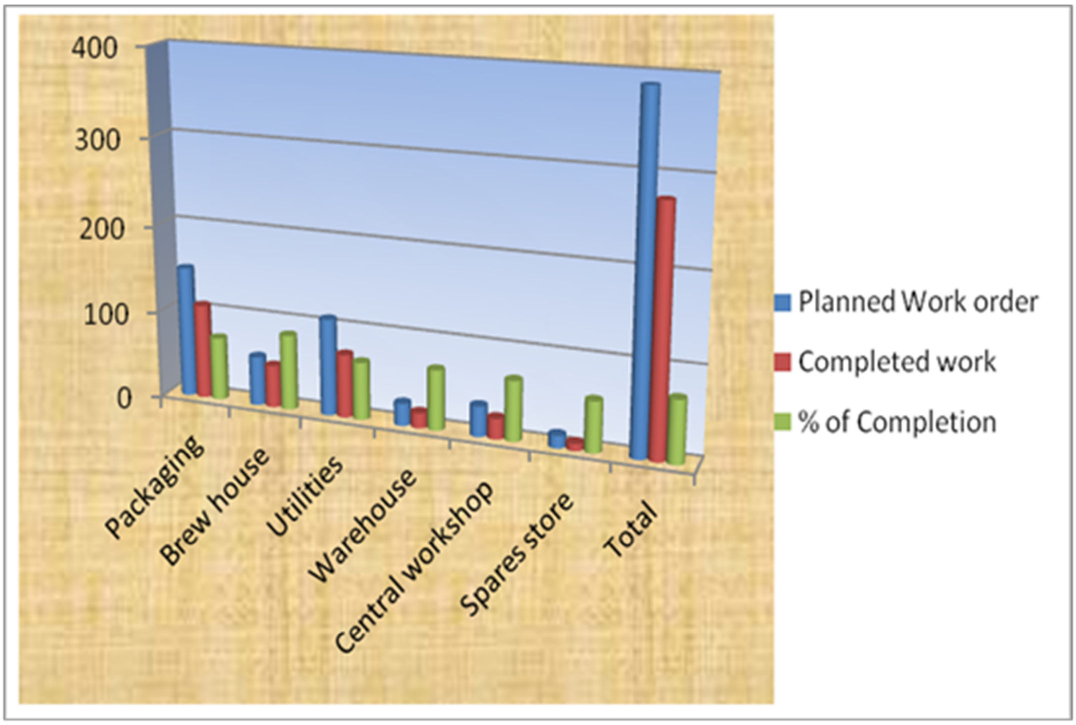

Figure 2.0 Maintenance activities in Company A.

The work order execution rate as showed above indicated that planned work is at the increase, more especially at the packaging department and utilities. A more focus was placed on packaging department, production line 4 to analyse the cause of equipment unavailability and downtime.

A solution finding tool called Pareto and 4 M- analysis were applied, considering machine, man, material and method as bad actors.

The Pareto Principle also known as the 80 /20 Rule refers to the fact that 80% of outcomes result from 20% of causes [11]. It is always represented by a chart called “Pareto Chart” which is a graphical tool allowing one to understand which categories result in the most outstanding issues, enabling one to target/focus the most troublesome areas first, in this case machine. Also, this can be done at an organization level, a project level, or a product level, amongst others.

63.3% of the production line unavailability/downtime was attributed to machine/equipment failure, which was later drilled down to washing machine constituting a good number of failures, hence reducing production line 4 uptime as shown in figures below [12].

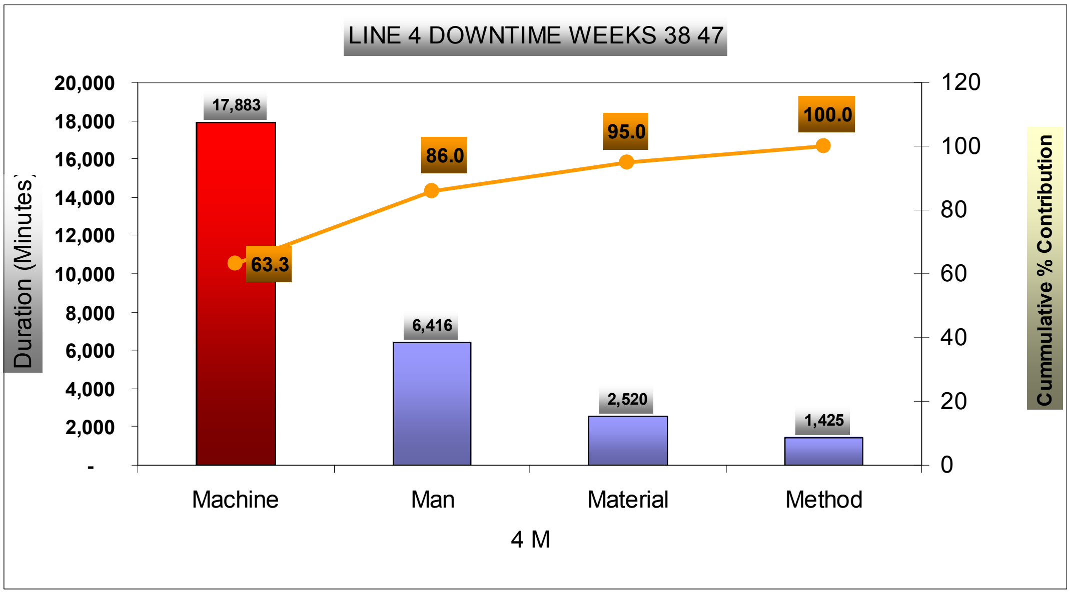

Figure 3.0 The equipment downtime recorded in production line 4 due to Machine, Method, Man and Material failure.

The machines that make up the production line include: Washer, Palletizer, Labeller, Filler, Bottle Conveyor, Pasteurizer and Unpacker. The rate of breakdown and equipment failure associated with machines in production line 4 (L4) are summarised in the Pareto chart below (Pareto of Breakdown Frequency, figure 4.0).

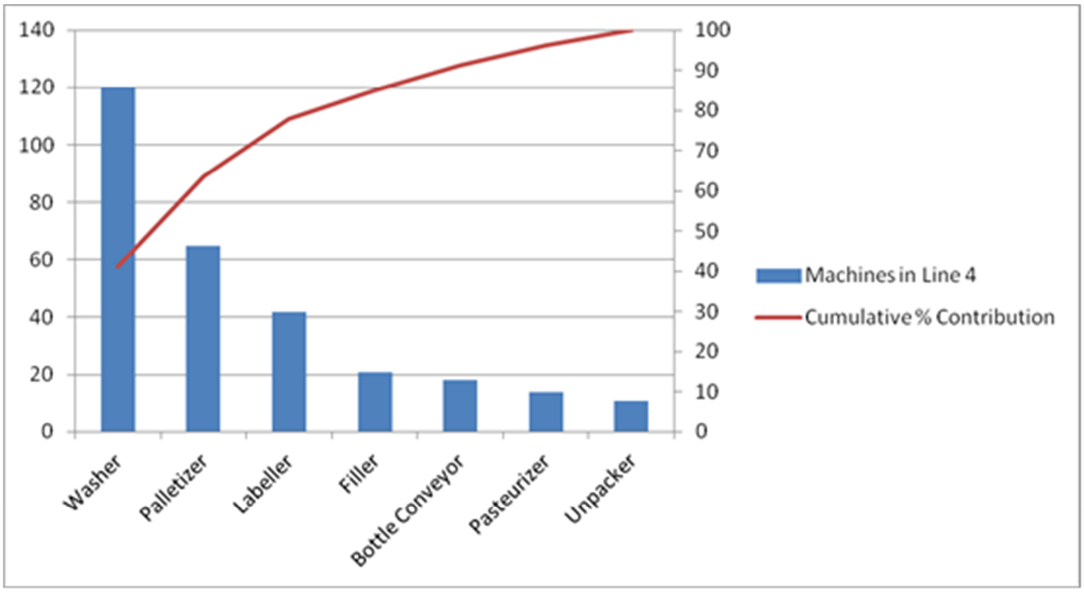

Figure 4.0 Frequency of machine breakdown.

Below also, is the Pareto analysis of the washer (washer assembly and sub-assembly) as picked from the machine analysis as the most troublesome equipment that needs to focus on, to improve production line availability. Hence, determination of the breakdown duration for the various assemblies of the washer is important, and it is illustrated in figure 5.0 and figure 6.0 respectively (Pareto of breakdown duration in Washer assembly/ sub-assembly).

Figures 5 and 6 below shows that the discharge mechanism in the Discharge section of the Washing machine is the cause of equipment and production line 4 downtime at different intervals. This means that, if we can utilise 20% of our overall maintenance time to focus on the discharge mechanism challenges, we will achieve 80% result, thereby improving equipment and production line availability.

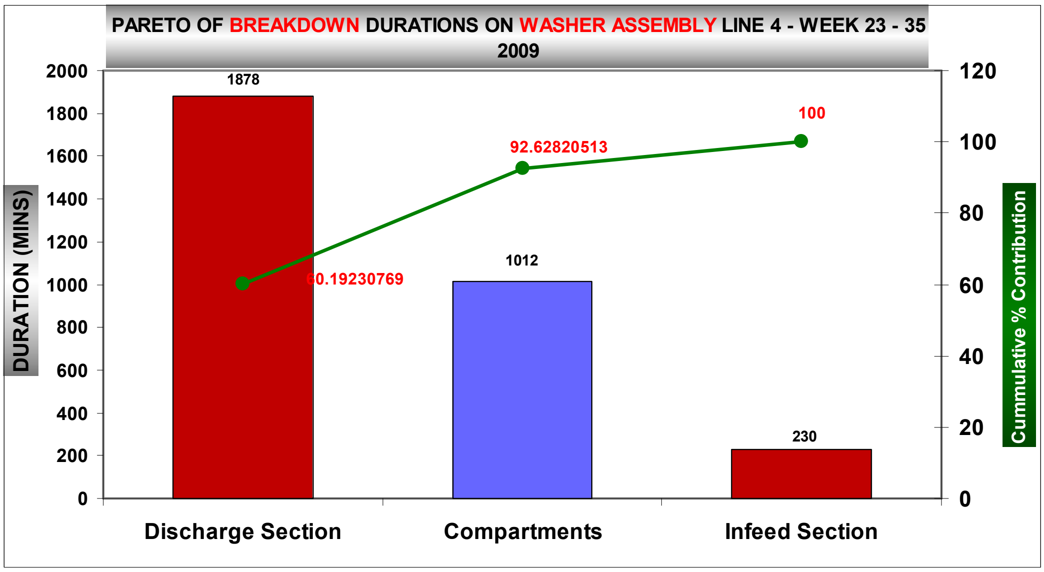

Figure 5.0 Breakdown of Washer assembly

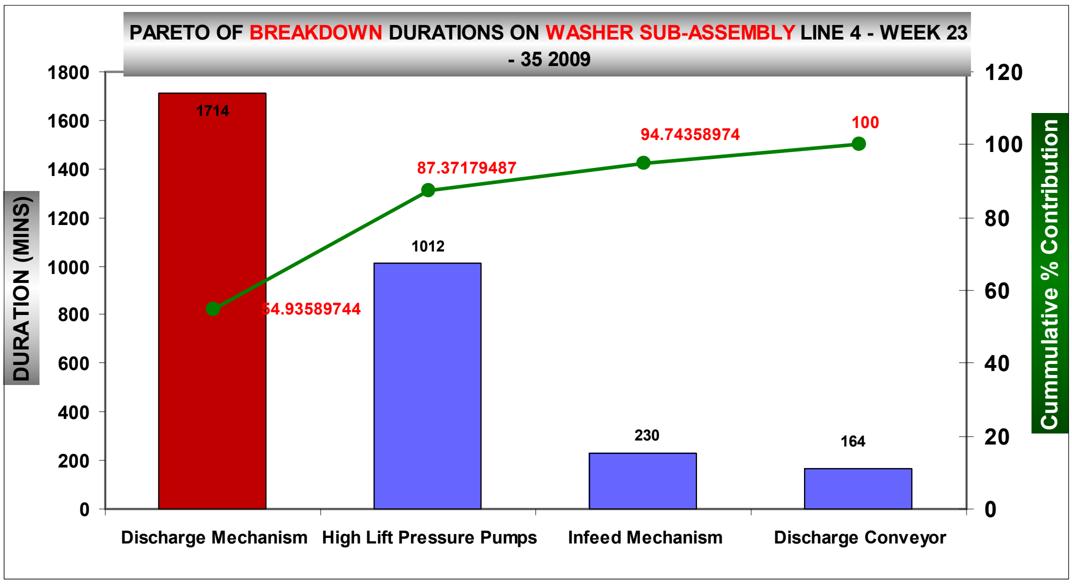

Figure 6.0 Breakdown of Washer sub-assemblies

(c) **Maintenance Challenges:**

- The major maintenance challenges in Company A are availability of spares and ageing equipment.
- Managing technical competence gap.

(d) **Improvements**: Deployment of Performance Improvement Tools for Problem Solving as follows;

- *Breakdown Seriousness Analysis*: This is a form of Root cause failure analysis.
- *Pareto Analysis*: This uses the Pareto principle, the idea that by doing 20% of the work order, you can generate 80% of the advantage of doing the entire job. Pareto analysis is a formal technique for finding the changes that will give the biggest benefits.
- *5 – Whys Analysis*: This is a simple technique that uses five different why questions to arrive at the root cause of the problem.
- *4- M Analysis / Cause and Effect Analysis*: This technique can identify, categorise and visually record the possible causes of a problem or effect. It will help to sort out and relate the interactions among the factors affecting a process. The categories chosen are generally related to Man, Machine, Materials, Methods and Environment as the case may be.

5.2 Company B

(a) Maintenance Policy: The maintenance policy of the establishment as observed are as follows:.

- All maintenance work must be approved before it is performed.
- Major maintenance work must be classified by priority.
- All maintenance schedules will be approved in advance by production; such approval then constitutes a commitment to comply with the schedule.
- A planned and approved schedule will be interrupted only by an emergency.
- Parts may not be removed from any non-operating unit and used to restore another unit to operating condition unless authorized by plant manager.
- Preventive maintenance and major repairs should be jointly planned and scheduled.
- Maintenance normally will be scheduled on a weekly basis.

(b) Maintenance Strategy: The strategy was majorly adopted based on the Original Equipment Manufacturer (OEM) recommendations on respective equipment. Hence maintenance plans were rolled out which are mostly calendar based, that is (Daily, Weekly and Monthly inspections of D-3412 generator, Boiler, Core winder, Slit rewinder etc).

(c) Maintenance Challenges

- Unavailability of spares
- Staff technical competence
- Ageing equipment
- Poor leadership commitment.
- Poor staff welfare.

(d) Improvements: Modifications and equipment change are done any time a serious equipment malfunction occurs continuously. A record of equipment failure/breakdown and production targets is provided in the spreadsheet shown in Table 1.0.

. The purpose of downtime analysis includes the following:

- ✓ To determine the cause(s) of unplanned stops and delays
- ✓ To determine ways to avoid or eliminate future occurrence
- ✓ To improve quality of maintenance
- ✓ To determine training needs
- ✓ Analysis of MTBF and MTTR
- ✓ Root cause failure analysis (RCFA)

Table 1.0 Target and Downtime analysis of Company B.

S/N	20/01/08	Daily Target	Actual Figure	Prod Variation	% Achieved	Downtime (min)	Downtime (hrs)
1	Logwinder 1	15600	9614	5986	61.63	386	6.43
2	Logwinder 2	14100	8726	5374	61.89	223	3.72
3	Logwinder 3	28500	12614	15886	44.26	159	2.65
4	X5 Logwinder	28500	11334	17166	39.77	247	4.12
5	Echo Logwinder	6000	2181	3819	36.35	302	5.03
6	Corewinder 1	1500	0	1500	0.00	1440	24.00
7	Corewinder 2	3000	1800	1200	60.00	76	1.27
8	Corewinder 3	3000	2040	960	68.00	76	1.27
9	Casmatic 1	1500	1150	350	76.67	386	6.43
10	Casmatic 2	1500	1100	400	73.33	223	3.72
11	Casmatic 3	1500	950	550	63.33	223	3.72
12	Casmatic 4	2100	1150	950	54.76	200	3.33
13	Casmatic 5	2100	1250	850	59.52	134	2.23
14	Casmatic 6	2400	1150	1250	47.92	183	3.05
15	Casmatic 7	2400	1200	1200	50.00	107	1.78
16	Double Casmatic	1200	0	1200	0.00	1440	24.00
17	Logsaw 1	1500	1150	350	76.67	386	6.43
18	Logsaw 2	3000	2050	950	68.33	223	3.72
19	Logsaw 3	3900	2400	1500	61.54	169	2.82
20	X5 Logsaw	6000	2350	3650	39.17	247	4.12
						6830	**113.83**

5.3 Company C.

(a) **Maintenance Policy**: "To define a maintenance strategy that guarantees asset integrity while optimizing equipment Availability, Reliability and Expenditure.

(b) **Maintenance Strategy**: The strategy was adopted based on the Consequence of Equipment Failure, Maintenance Strategy Decision Logic, Risk Matrix and Reliability Centred Maintenance (RCM). Risk based Inspection (RBI) can equally be used to roll out maintenance plans, frequency and matrix of particular equipment.

(c) **Maintenance Challenges:**

Maintenance challenges were similar to those highlighted in the other two companies ranging from unavailability of spares, ageing equipment, long time of placing contracts and ordering of critical spares from Supply Chain Management (SCM).

(d) **Improvement:**

- Total Reliability team" (TR) constituted to focus on ageing equipment.
- Deployment of Performance Improvement Tools for Problem Solving as follows;
  - ✓ Root cause failure analysis (RCFA)
  - ✓ 5-Whys
  - ✓ Apollo etc.

6.0 CONCLUSION AND RECOMMENDATIONS.

System optimisation is the primary concept of this work which absolutely implies zero tolerance in terms of equipment breakdown/failure, maximisation of production and credible increase in facilities availability at the lowest cost through the application of highest quality/specification and safety standards.
To achieve the above, it is, therefore, important to design quality and maintenance during the project initiation and conceptual phase. A well-designed production line has some distinct features, which include the following;

- Ability to consistently produce products of the desired quality.
- Efficient production process.
- Easy to operate and maintain
- Guaranteed reliability.

Also, equipment sizing, selection, maintainability, maintenance strategy, spares availability, required expertise are essential for consideration.
System design should be done to eliminate avoidable breakdowns especially on the rotating equipment, reduce downtime and maintain high equipment availability at all time. Other specific recommendations to enhance optimal production with little or no equipment/machine failure/breakdown include the following:

(a) Application of N+1 philosophy: This is a strategy of providing a spare production line during the process design. N means the number of the production line or equipment needed for operation while +1 means additional one that will serve as spare, popularly refer as "Duty standby machine"
The purpose of the standby equipment is to ensure a high level of process system availability.
(b) Effective equipment condition monitoring [Equipment health check]: Most failure modes are not age-related. However, most of them give some sort of warning that they are in the process of occurring or are about to occur. If evidence can be found that something is in the final stage of failure, it may be possible to take action to prevent it from failing completely and / or to avoid the consequences.
Condition monitoring is the continuous or periodic measurement and interpretation of data to indicate the condition of an item to determine the need for maintenance.

(c) Embarking on Strategic inventory control: The major maintenance challenge that cut across all the production and manufacturing companies is spares availability. For the goal of maintenance to be realized, adequate and only the needed spare parts must be available at all times. The spare parts purchase must be integrated with the work order system to ensure availability and cost determination of work done.

(d) Adoption of computerized maintenance management system (CMMS)
The computerized maintenance management system (CMMS) is a modern tool (software) used for Plant Maintenance (PM) management [13].
It is used for work, assets, PM and spares parts management. It confers the following advantages:

- Everyone accesses PM information on-line
- Improves speed of maintenance activities
- Better management of data compared to manual form.
- It is user-friendly once understood.

CMMS interplays with the maintenance strategy, plan, procedure/task list, spares, and generates work order according to plan as at when due.

(e) Aggressive pursuit of total productive maintenance (TPM): Total productive maintenance embodies continuous improvement and care of assets to ensure that their operation at optimum efficiency becomes an organizational value driver. One of its objectives is reducing an overall production cost, including how cost-saving happened by finding the root causes of machine worn out and failure, then implement a precise and proactive countermeasure.

(f) Employee competence development and motivation: In the life of an organization, employees are the most valuable asset one can think of, but they are liabilities unless trained to meet the required competence level.

Competence development, adequate training and re-skilling of the relevant people are very essential in managing the life cycle of equipment and facility. Competence is a combination of knowledge, skills and attitudes that enable performance at required level. These training can be off or on the job, formal or informal and at times be tied to career progression. In a typical production line, specific equipment vendor or OEM training is seriously encouraged, as this will expose the operators to the basic and in-depth knowledge of the equipment.

Also, it is advisable not to compromise training with cost as in the case of most of our indigenous companies because it has a long term laudable dividend.

More so, training should be continuous, fit for purpose and have a special budget provisions in the annual business plan of the organization.

References

1. John M. Nicholas (1998) Competitive Manufacturing management. McGraw-Hill, International Edition.
2. www.businessdictionary.com/maintenance
3. Okah B.E (1996) The Science of Industrial Machinery & Systems Maintenance. W. Girardet Press (W.A) Co. Ibadan, Nigeria.
4. www.schooldude.com
5. www.wisegeek.com/corrective maintenance.htm
6. www.en.wikipedia.org/wiki/Preventive_maintenance
7. www.maintenanceresources.com
8. www.armstronginternational.com
9. Narayan V, J.W.Wardhaugh and M.C. Das (2007) 100 years in Maintenance and Reliability.
10. Narayan, V. (2003) Effective Maintenance Management, Risk and Reliability Strategies for Optimizing Performance.
11. Maintenance Manual of Nigeria Breweries Plc (2008)
12. Maintenance Journal of Star paper Mills Ltd (2003).
13. Operations and Maintenance guide of SPDC (2004).