Inherent Factors Affecting the Effectiveness of Maintenance Using Root Cause Analysis. A Case Study

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Abstract

The downtime experienced in the Nigerian manufacturing sector has become a threat to its existence due to the cost implications. Despite different maintenance strategies, the results have not been too promising, hence the need to understand the factors causing downtime and effect on machine availability. Root cause analysis of two years breakdown data of a Beverage Company in Nigeria using the Five Why approach reviews that man and method are the predominant cause of failures in a production system which are both a measure of the organizational workforce competency. The result shows that 95 per cent of the total downtime was due to man and method problems while a cumulative of 92 per cent of the total number of failures could be linked to man and method. Man and method issues are functions of skill of the workforce with the effect is obvious in the percentage of breakdown and the incurred downtime in restoring the failure on a machine.

Keywords
Root Cause Analysis, Five Why, Breakdown Analysis, Maintenance, Downtime

1. Introduction

Competitive pressure has forced companies to use their equipment's durability and efficiency as a strategic advantage. Executives in asset-intensive industries find unforeseen physical asset failures to be a key operating threat to their companies (Meissner et al., 2021). In dynamic manufacturing supply chains, unintended downtime can be destructive and imposes high costs due to forgone efficiency. To improve the efficiency and durability of equipment, maintenance activities such as repairs or replacements, system upgrades (consider changes in production pace, for example), scheduled overhauls and corrective measures are carried out (Rokhforoz & Fink, 2021). According to the way these interventions are applied, different maintenance policies can be distinguished ranging from conventional corrective maintenance to more sophisticated preventive maintenance policies such as condition-based or predictive maintenance.

Typically, there is a disarray in alignment with the expected benefits from maintenance strategies and attained performance. While practitioners may seem to be doing things right, with various maintenance activities in place to improve system reliability, the effectiveness is still questionable. Effective action plans for reliability and performance improvement require the identification of shortcomings to elucidate the pattern of flaws. Maintenance indices such as mean time to repair (MTTR), availability and mean time before failure (MTBF) measure the effects of failure but do not illuminate the pitfalls in the maintenance activities.
Consequently, there is a need to uncover the issues affecting equipment performance in addressing maintenance pitfalls and to generate effective action plans for maintenance management, thereby maximizing the achievable benefits. To reduce machine downtime, it is imperative to have a detailed understanding of the different factors that contribute to the machine’s unavailability.

This study aims to determine the predominant elements affecting the effective application of maintenance policies in a Beverage Company in Nigeria, based on the root cause of failure analysis and understand the link between different root causes of problems to their respective source in the production system.

2. Literature Review

The main question that maintenance management faces is whether its output is produced both effectively, in terms of contribution to company profits, and efficiently, in terms of manpower and materials used. In manufacturing, maintenance cost is usually a major concern to stakeholders and optimization of this cost is a key performance index of the maintenance management team (Cavalcante et al., 2018; Christer et al., 1998; Zhao et al., 2017). The ability to predict critical failures that may lead to long downtime is a key factor in reducing the overall cost along the supply chain (Lin et al., 2013). Any breakdown that occurs during production will lead to a disruption in the supply chain, hence the need for adequate maintenance (Ascher & Feingold, 1984; Fiondella et al., 2015). Maintenance is a continuous process and demands continuous improvement to achieve the desired efficiency and effectiveness at a minimal cost (Berrade et al., 2017; EMC Corporation, 2015). Two improvement approaches are widely adopted in maintenance namely; Total productive management (TPM) and Reliability centred maintenance (RCM) (Singh et al., 2013). TPM is a continuous improvement approach (Chan et al., 2017a) aimed at total eradication of losses in all processes (Brah & Chong, 2004). The losses targeted by the TPM methodology include breakdown, setup and adjustment, idling and stoppage, reduced speed and defects in the process (Ahuja & Kumar, 2009). RCM focused on improved design and technology based on the systematic assessment of the system maintenance needs derived from a holistic understanding of the functionality and the different failure mode and effect analysis (FMEA) associated with that system (Siddiqui & Ben-Daya, 2009), (Chan et al., 2017b). Common to these problem-solving tools is the root cause of failure analysis. Root cause analysis (RCA) refers to both a philosophy and a set of specific techniques used to find the basic reason(s) for the occurrence of unwanted situations, problems, or accidents (Dorsch et al., 1997). RCA is a step-by-step, research-based and structured approach used to identify the reason for the unwanted situation or problem. “Step-by-step” indicates that a systematic procedure is required to perform this approach. In addition, “research-based” refers to the need for planning, time and effort to conduct it. Hence, to find the main causes, everything related to the unwanted situation should be studied. According to the philosophy of this reactive problem-solving approach, every situation (event, accident or problem) is preceded by another situation that causes it. The core ability of RCA is to identify and prevent the unwanted situation or a problem from reoccurring rather than trying to fix it (Sweis et al., 2019). Thereby, the aim is the possibility of eliminating the root causes to prevent any probable reoccurrence. In addition, after deleting these root causes, monitoring the symptoms will assist to check the status of the unwanted situation. Chen (2013) introduces an autonomous preventive maintenance approach that integrates FMEA techniques with root cause analysis to improve manufacturing and equipment efficiency as well as support workers with decision support. The method is carried out manually by teams of experts and are applied to and verified by means of a use case within the semiconductor industry (Chen, 2013). Sharma and Sharma (2010) present an approach for system failure behaviour analysis and maintenance decision making using root cause analysis, FMEA and fuzzy methodology. They provide an integrated framework to model, analyse and predict the behaviour of industrial systems in a more realistic and consistent manner and to plan suitable maintenance strategies (Sharma & Sharma, 2010).

Despite different maintenance strategies in literature, the downtime experienced in the Nigerian manufacturing sector from breakdowns has become a threat to its existence due to the cost implications. The major factor that contributes to the accumulation of failures is the nature of maintenance activities which include the utilisation of alternative maintenance approaches and knowledge gap in the maintenance team in carryout efficient maintenance. This factor, to the best of our knowledge, is yet to be addressed in detail by literature.

3. Methods

3.1 Research into organizational maintenance practice

The maintenance of the packaging lines of the Beverage company was understudied for two years to understand the reason behind the ineffectiveness of maintenance strategies in place. By definition, the packaging is the process of putting beer/malt into a package. The packaging line consists of several machines linked together by a conveyor. Line layouts and speeds are the keys to good line performance based on optimum efficiencies and manning levels. Figure 1 below shows a packaging line layout with machines in V-Curve with the curve used to represent conveyors linking the machines.

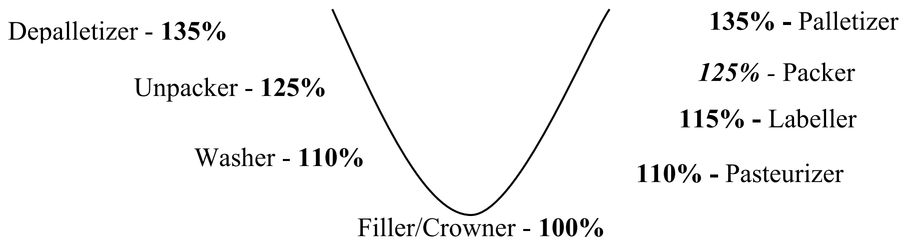

Figure 1. Line Layout (V-Curve)

Maintenance in this case study is conducted by a planned maintenance (PM) team. The maintenance team shown in Figure 2 consists of four maintenance managers and the Engineer Manager (EM) is the head of the department. The Engineer in charge of Planned Engineering (EPE) manages the computerized maintenance management system and tracks all the indicators including work order executions ad backlogs. The Planned Maintenance Engineer (PME) is responsible for the maintenance of the production line. The Brewery Automation Engineer (BAE) serves as a specialist consultant for automation-related problems. The Automation Engineer (AE) is a specialist in machine automation. The Team Leader is responsible for job planning and team administration. The Mechatronic Technicians are divided into two groups. The first serves as planned maintenance technicians assigned to a particular machine or section. They are expected to have detailed knowledge of maintenance on the assigned equipment. The second group are referred to as the Shift Mechatronic Technicians. They are generalists on all the machines with good mechanical and automation backgrounds. They work with the operators on a shift basis and take out minor issues that could result in unplanned downtime. They are responsible for the quick escalation of major issues to the machine leaders and the automation engineer or prompt support. The operator is in charge of machine operations and autonomous maintenance such as cleaning, visual inspection, lubrication and tightening (CILT).

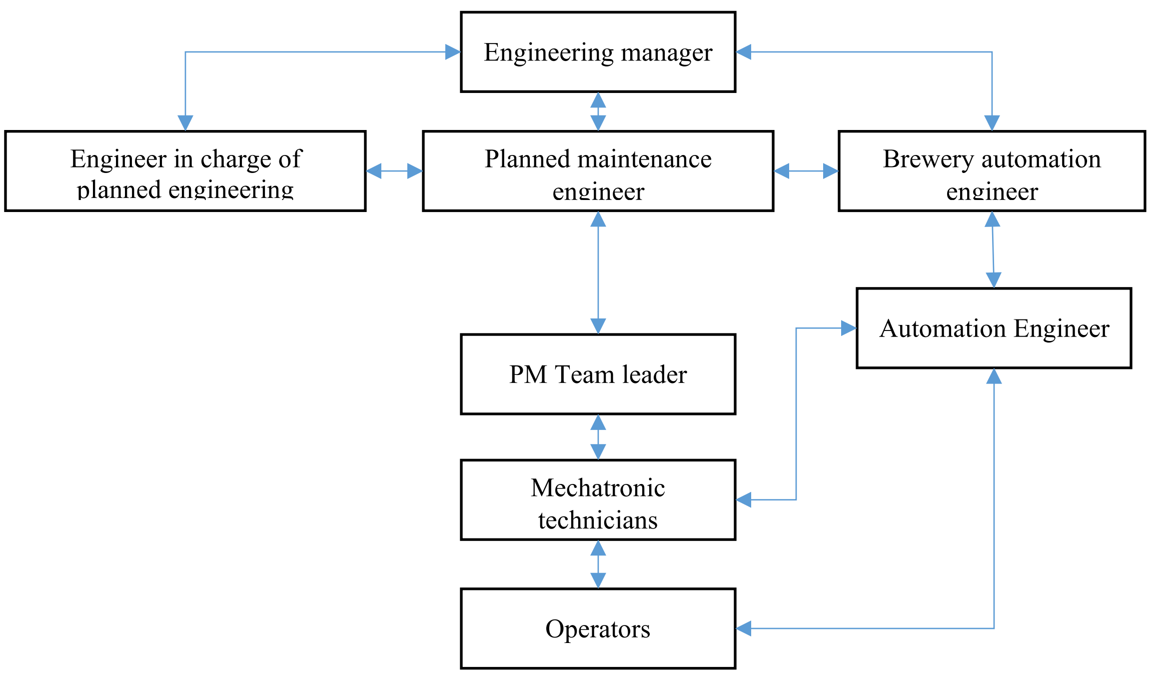

Figure 2. The maintenance team structure with information flow.

In a nutshell, the PM team is responsible for all the preventive and corrective maintenance required for production and relies on a well-defined preventive maintenance policy with a unified problem-solving tool for failure eradication. The maintenance policy states that the company does not implicitly or explicitly practice breakdown maintenance. This implies that the only recognized type of maintenance is preventive maintenance. The policy also specifies an alternating weekly production stoppage for detailed maintenance and inspection stop for detailed inspection and trivial repairs. Maintenance planning and documentation are carried out using computerized maintenance management software (CMMS). Systems Applications and Products in Data Processing (SAP) is the CMMS used in this study. Following the preventive maintenance policy, every piece of equipment is registered on SAP. The maintenance plan document plan specifies the detailed actions on a task list to be executed on each machine to keep it in the basic condition is developed and uploaded to SAP and scheduled according to the predefined interval

SAP as a maintenance management tool is designed to receive work requests as a notification which are converted to work orders by technicians for execution. The sources of inputs to maintenance are thus from machine operators' observation and inspection by technicians. These two inputs are classified as corrective actions because the observed deviations are to be repaired and are not part of the preventive maintenance plan programmed for the equipment on SAP. It is expected that the ratio of system generated work order to the corrective work order should be 70:30. With this scenario, the planned maintenance team focus more on carrying out planned inspection and maintenance rather than solving breakdowns that affect the smooth flow of production. Based on the machine task list, three types of preventive maintenance activities are defined as follows;

i. Running inspections

Running inspection is also referred to as condition monitoring. It is a detective approach to ascertain the condition of the machine while in operation. This inspection is very important and serves as a major input toward maintenance planning for the PM day stoppage.

ii. Inspection stops

Inspection stops demand that the machines are stopped with all the energy sources locked out and tagged out (LOTO) for safety. During this period, a detailed inspection is carried out on assembly and subassemblies up to component level. Minor repairs and replacement can be done while major repairs discovered can be scheduled for the planned maintenance day for corrective repair.

iii. Planned maintenance day

Planned maintenance day is an extended production stoppage for the proper execution of planned preventive and corrective maintenance activities. The machines are handed over to the maintenance team using a plant release form from the operator on duty, duly signed by the manager. It is expected to have above 70% preventive maintenance tasks and less than 30% corrective maintenance actions. After maintenance, the machines are tested by the technician together with the operator and handed over to the production team for usage.
Despite structure maintenance programmes in place, there is a need for Optimisation and continuous improvement to enhance profitability by reducing losses arising from unplanned downtime.

3.2 Breakdown definition

For packaging Line Overall Performance Indicator (OPI) measurement, all machines are considered as one, thus stoppages of the line are exclusively measured at the lowest point of the line V graph, where manning is available. The filler is, therefore, the designated point of measurement for line OPI as shown in figure 1. For the time measurements at the filler with an automatic reporting system, a classification into breakdown or speed losses is required, otherwise, incorrect data is used for both breakdown as well as speed losses.
The breakdown is defined as the Stop of a machine/system for more than 5 minutes as a result of mechanical, electrical / instrumentation failure of components, subassemblies or machinery and/ or control system. By this definition, any stop that is less than 5 minutes is regarded as a minor stop or performance loss while stoppage up to 30 minutes is selected for detailed root cause analysis based on a seriousness level of stoppage defined by the company standard. Line data software is a line management software for line data collection. The data recorded include the line overall performance indicator (OPI), speed losses and breakdown information. Table 1 shows a data capture report from the software.

Table 1. Line Data Software for Downtime Data Capture

Downtime Category	Duration (minutes)	Frequency
Unused time	49440	98
External stop	5045	562
No Orders, No Activity (NONA)	564	5
Non-team maintenance	11442	39
Change over	6267	167

Breakdown	27641	974
Speed loss	50465	12252
Reject and rework	0	0

3.3 Root cause of failure analysis using Five Why

Five Why (5 whys) is a problem-solving method that explores the underlying cause-and-effect of particular problems. The Five Whys method was originally developed by Sakichi Toyoda, the founder of Toyota Industries. The primary goal is to determine the root cause of a defect or a problem by successively asking the question "Why?". For systematic analysis, the first thing to do is to make a description of what the problem is thereby describing the functional failure. A functional failure is defined as the inability of an asset to fulfil one or more intended function(s) to a standard of performance that is acceptable to the user of the asset. Secondly, the problem is investigated to understand how it occurs. To understand what went wrong, one must first understand how something should go right: The working principle and the basic conditions needed to be in place. With this knowledge, the failure mode can be identified. The failure mode is the event or situation that causes a functional failure. The third step is the root cause analysis itself. The root cause is the level of causation at which it is possible to define a countermeasure. The 5 Why analysis is a problem-solving tool that allows the problem solver to identify the root cause of a problem. Here an initial list of causes (failure modes) is generated followed by a sequence of 'Why' questions for each failure mode. (Why1-1, Why1-2, Why1-3 etc.). Each 'Why' is then verified to confirm whether it is a possible cause that requires further investigation or it is not a cause that will allow it to be disregarded. This process is repeated until the root cause is identified. This normally requires 'Why' to be asked at least 3 times and sometimes up to 5 times. Benefits of 5 Why analysis include simplicity (i.e., this is not a highly technical process and yet is highly effective), helps to identify the root cause of a problem and can lead to an understanding of the relationship between different root causes of a problem. An example of 5 Why analysis template is shown in Figure 3

5 Why sheet														
	Potential causes										Actions			
Failure Mode	Why (1)	Check	Why (2)	Check	Why (3)	Check	Why (4)	Check	Why (5)	Check	4M	CORRECTIVE ACTION	Check	PREVENTIVE ACTION	Check

Figure 3. A Five Why Template

The logic of 5 why analysis in arriving at the root cause of a problem is summarised in Figure 4 below. By definition, man's problems emanate from the worker. Problems with root cause issues traced to operational procedures are referred to as method problems. Material related problems are due to product and components design. Machine problems are due to machine design and workstation layout (Favi et al., 2017), (Coccia, 2017).

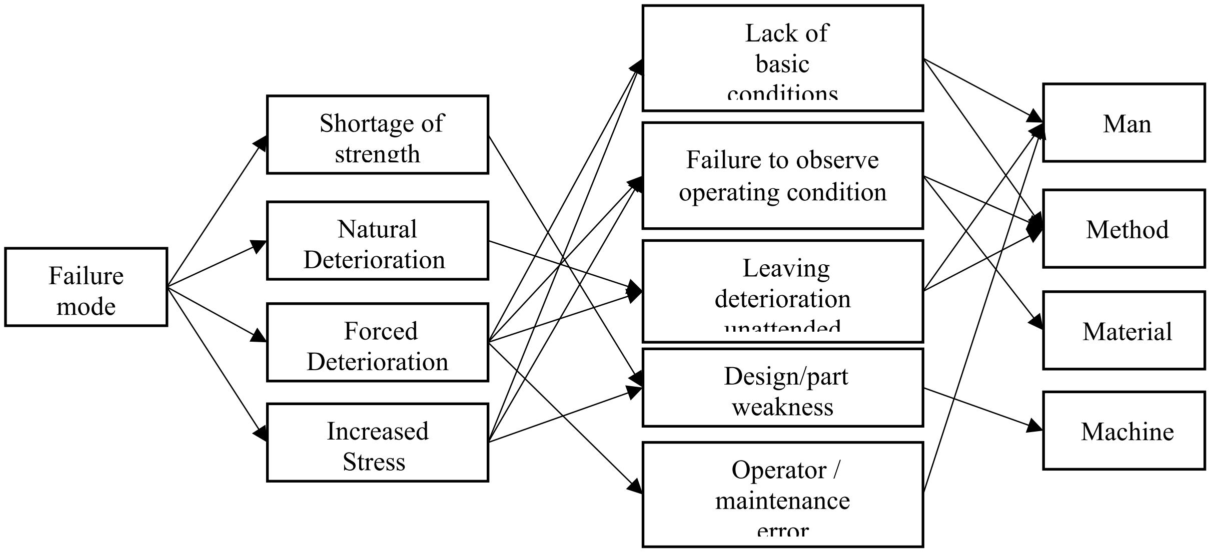

Figure 4. The logic of 5 Why analysis

The design and implementation of this countermeasure is the fourth step. The countermeasure is the action that corrects the root cause. This is also called corrective action. As soon as a countermeasure is implemented, this should have an impact on the failure mode. To verify if the countermeasure is effective, the impact on the failure should be proven and closely monitored for some time.

4. Data Collection

Data from the breakdown is obtained through detailed analysis with input from the operator on duty, the shift technician fixed the problem. Some of the data obtained include the tie of breakdown, the prior sign, the functional failure, the accrued downtime from the time of failure to restoration and a description of how the problem was solved etc. These data act as a guide for the root cause of failure analysis. Table 2 is a list of the analyzed breakdown in 2019 and 2021 with details of the failure mode, the root cause and the category of the root cause of failure.

Table 2. Breakdown Analysis (2019 to 2021)

Machine	Downtime(mins)	Failure Mode	Root Cause	4M
Filler	60	Derailed can transfer chain	Spring-loaded chain tensioner loosed and not returning	Method
Unpacker	140	Damage multi-core cable	Strand of cable exposed	Method
Filler	42	Misaligned crown cork star	Long usage	Method
Filler	42	Misaligned crown cork star	Wrong timing of the star	Method
Shrink Wrapper	43	Group 2/3 over temperature	Prolong usage	Method
Washer	54	Gear sensor not sending feedback	Lack of lubrication	Man
Packer	69	misaligned grabber head	Lack of inspection	Man
Washer	51	Damage manifold seal	The wrong seal used	Man
Packer	39	misalignment of grab head sensor	Not properly tightened	Method
Washer	105	Fallen back bottle from	No lubrication point on the	Machine

		carrier	bearing	
Washer	40	Open circuit multicore cable	Stress on cable at the turning point of op panel	Machine
Washer	40	Worn out Coupling	Locally fabricated	Man
Packer	62	Misalignment of grab assembly	Improper tightening of the bolt	Method
Filler	42	Misaligned sensing plate	Most plates fabricated locally	Man
Labeler	47	Bottle explosion inside the machine	Poor handling	Method
Washer	50	Depressed emergency push button	Operator oversight	Man
Labeler	132	Wrong position of Anvil	Wrong position of Anvil	Method
Labeler	37	Short circuit photocell	Photocells are not covered when cleaning	Man
Filler	57	Collapse bearing	No provision for bearing lubrication nipple	Machine
Labeler	79	Gripper not picking label	magazine wrongly position on the pallet	Man
Labeler	60	Misaligned pallet magazine	Excessive tightening of the bolt	Method
Washer	42	Hooked piston	Lack of lubrication	Method
Filler	75	Broken down winding insulation	No proper calibration for damping	Method
Seamer	76	Hooking can at can lid	MS-can lid exhausted	Man
Machine	Downtime(mins)	Failure Mode	Root Cause	4M
EBI	39	Bottle jam at discharge	Pressure regulate at 3bar instead of 4 bar	Man
EBI	90	Disposition mask on camera	Lost programme calibration	Method
Labeler	74	collapsed glue roller bearing	used beyond replacement schedule	Method
Washer	60	Damage sensor plug pin	Broken direction slot	Man
Filler	30	Misaligned transfer plate	Worked loosed bolt and nut	Method
Unpacker	30	Massive falling bottle along expacker to the washer	The sensor on the shaft was not positioned properly	Man
Labeller	374	gripper cylinder cam timing delayed in picking label from glue pallet	cam not properly timed	man
EBI	60	misaligned jam sensor	inconsistent bottle shape	Material
Palletizer	100	rubber carrier pulled out	deterioration	method
Packer	93	Frame guide not centralised with the grab assembly.	Worked loosed hanger holding bolts/nuts	Method
Packer	119	broken agitator support	the joint was not properly welded	Man
EBI	80	Jam sensor misaligned	Loose photocell. Reflector surface too narrow	Man/Machine

Palletizer	185	dirty photocell reflector	reflector not cleaned	Man
Palletizer	70	cable cut	cables not adequately protected	man
Pasteurizer	92	blown mains fuse	no planned maintenance for the fuses	Method
	805	lost containers	jerking conveyor	Man
Labeller	206	A short circuit inside Asi-connector	water ingress	Man
Filler	98	worn-out agitator hook	Wrong adjustment of the hook	Man
Check Mat	139	incorrect rejector push-out	position settings not correct	Man
Filler/Crowner	120	cork transport belt cut.	no established replacement plan	Method
Unpacker	43	Grab assembly jamming the frame guide.	In used for a long period (25 years)	Method
Pasteurizer	62	Motor pinion dropped inside the gearbox	incorrect assembly	Man
Empty Bottle Inspector	81	Broken strobe glass	Torn/ cut rejector resilient pad	Method
Washer	40	discharge finger hooked	Worked loosed holding bolt	Method
Filler	150	crowner bottle seat worked loosed	not firmly tightened	Man
Packer	112	main drive chain cut	long usage	Method
Pasteurizer	119	falling bottles from the machine	high temperature	Man
Palletizer	110	slant bard chain jerking	sprocket teeth were worn out	Method
Machine	Downtime(mins)	Failure Mode	Root Cause	4M
Packer	31	Multipin connection socket pulled out	Design weakness	Machine
Washer	105	discharge finger hooked	bad bottle pocket	Method
Palletizer	70	rubber carrier pulled due to bent camber	jam due to falling crate	Method
Labeller	218	Gripper cylinder malfunction due to misalignment of bottle present sensor	Water splash on the reflector	Method
Filler	177	vacuum pump overheating	the suction point was blocked with labels	Method
Unpacker	160	Excess crates photocell not sensing the reflector	Water ingress into the reflector	Man
Washer	34	Bottle jam due to bottle carry over in pocket	damaged bottle carriers	Method
Crate Conveyor	50	crate conveyor(plastic) broken, the chain cut	leaving deterioration	Method
Palletizer	70	foundation bolt of crate divider drive worked loosed.	High-speed settings on frequency converter	Man
Palletizer	51	palletizer could not grab crates due to bent gripper finger	malfunction of crate photocell counter	Method

Labeller	250	intermediate star wheel jam after a changeover	star wheel did not set	Man
Palletizer	70	Misaligned safety barrier photocell	Slack fasteners	Method
EBI	56	Broken green belt.	Replacement plan not effective equipment condition not effectively monitored	Method
Palletizer	39	Gripper device one not open	Gripper head not balanced	Method
Filler	118	Infeed worm misaligned	Not adjusted during a change over	Man
Palletizer	80	Bent roller	worn-out pin	Method
Pasteurizer	178	short circuit	damage seal	Method
Palletizer	34	Broken cable for the final position sensor	Difficult to inspect	Machine
Labeller	32	firing point not aligned with firing position on the label.	label design different	material
Labeller	129	Worked loosed grubs crew	Grub screw not in place after maintenance	man
Palletizer	102	crate pusher hanging bolt worked loose	the bolt is shot	man
LaserJet Labeller	129	Burnt controller chiller cable	under-rated power link	Man
Filler	50	collapsed bearing	Lack of lubrication	Man
Washer	120	The steam trap ball got punctured	No inspection regime for the steam strap ball	Method
Packer	60	Driveshaft not driving the sprocket	It was used for a long period (2years)	Method
Machine	Downtime(mins)	Failure Mode	Root Cause	4M
Palletizer	170	crate diverter stud base got broken	Broken joint	Method
Labeller LaserJet	90	Melted power cable link	Under-rated power link	Man
Palletizer	70	Pallet drive 26m7 short circuit internally	Exposed cable conductors	Method
Palletizer	34	Diverter rod disconnected from diverter pneumatic cylinder	Loose rod/cylinder connector	Method
Filler / Capper	60	Missing guide rails on heads no_ 4,5 and 8	Work loose cylindrical head	Method
Palletizer	150	Sensor not activating pusher	Grease on the sensor surface	method
Palletizer	140	Wrong formation of crates	Damage of tensioned wear strip	Method
Labeller	60	Bottle present sensor. Reflector worked loosed bolt.	Worked loosed bolt	Method
Blow Moulder	600	Missing CP configuration in PC station	The supply circuit breaker switched off during maintenance	Man
Packer	210	Guide frame sensor damage	Sensor too close to the frame	Man

Washer	250	Discharge mechanism sensor cable damage	cable too short	Man
Palletizer	60	Wrong turning of crates	Weak strip	Method
Palletizer	150	Roller internal thread is worn out	Misaligned photocell	Man
Palletizer	240	No sensor signal	Collapsed bearing/ leaving deterioration	Method

5. Results and Discussion

The result of the two years breakdown analyses is shown in Table 3. The downtime is linked to the associated 4M with their count to determine the predominant cause of machine breakdown affecting production as shown in Figures 5 and 6.

Table 3. Result of breakdown Analysis

4M	Downtime (minutes)	Count of 4M
Machine	267	5
Man	5262	36
Man/Machine	80	1
Material	92	2
Method	4061	47

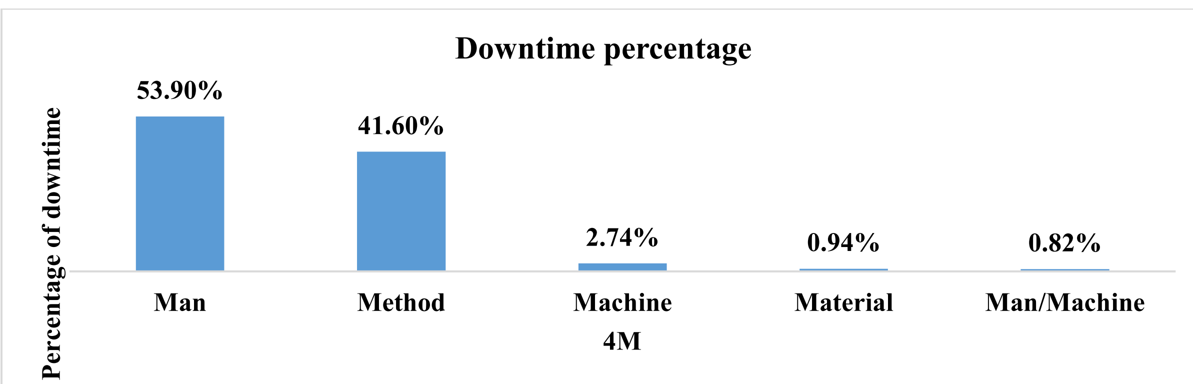

Figure 5. Percentage of downtime and their corresponding 4M root cause

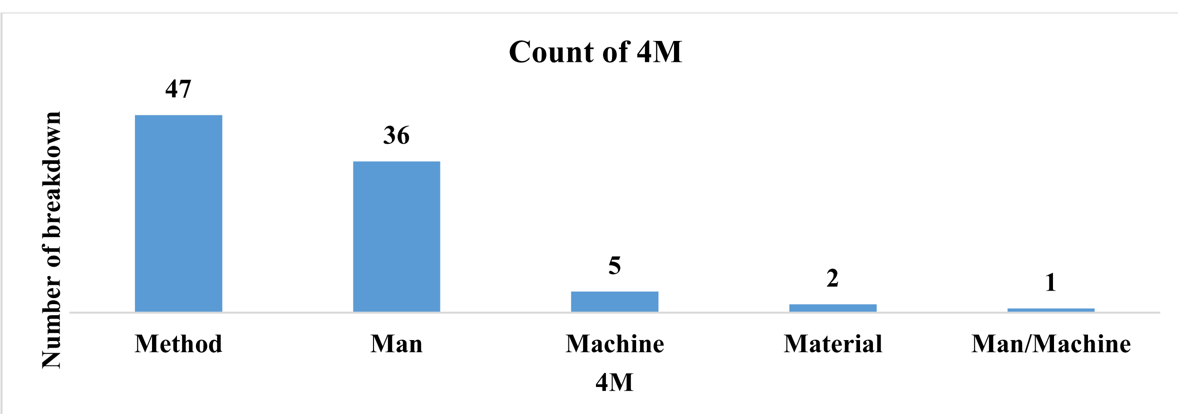

Figure 6. Number of analyzed breakdown data and the corresponding 4M root cause

Even though a production plant is applying the correct maintenance techniques, the expected result may still not be achieved as there are other factors affecting the applicability of maintenance strategies. From the analysis of the major breakdowns in the plant, man and method are the cuprite and both are a function of the functional competency of the maintenance team in following the prescribed maintenance system. Figure 5 reviewed a 95 per cent of the total downtime was due to man and method problems while a cumulative of 92 per cent of the total number of analyzed failures were traced to man and method as shown in Figure 6. Man and method issues are functions of skill and attitude of the workforce and thus the effect of competency is obvious in the percentage of breakdown that is attributed to man and method and the incurred downtime in restoring the failure on a machine.

6. Conclusion

Analyses of breakdown data without understanding the underlying failure mechanisms will lead to a wrong conclusion and subsequent recurrence of failure. The failure mode of any breakdown must be linked to the root cause before such failure can be permanently eliminated by the implementation of appropriate countermeasures. From our study, over 90 per cent of downtime experienced during production was attributed to either man or method. Man and method issues are functions of skill and attitude of the workforce in following a defined maintenance system. Deficiency in either skill or attitude greatly affects the resulting functional competency as the performance of a technician during evaluation may not exactly represent the field performance. Thus, the major factor that contributes to this deviation is the nature of maintenance activities which include the utilization of alternative maintenance approaches and the knowledge gap in the maintenance team in carrying out efficient maintenance regarding a Nigeria case study.

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Biographies

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