Risk-Based Assessment on Failure Rates of Mechanical Equipment of Public Water Treatment Plants

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Abstract— There is an increasing trend towards using the concept of risk assessment as an important tool in the Industry. Focus is placed on eliminating the unexpected failures which cause unnecessary costs and the production losses failure rates. Reliability and risk level of the mechanical equipment were computed in order to establish the equipment criticality and estimate the associated risk level of the critical equipment. Risk level calculated as the product of the probability of the equipment failure and the consequence of its failure on the entire water treatment production line. A schema for total maintenance of the mechanical equipment was then derived from the system analysis. The study showed that the failure of mechanical in water treatment plants ranged from 5 to 49%. The intermediate service pump had the highest critical index of 81 with occurrence rating of 9 out of 10 and severity rating of 9 out of 10; alum saturator had the least critical index of 12 with occurrence rating of 6 out of 10 and severity rating of 2 out of 10. The developed model describing the impact of each mechanical equipment on the water treatment plant is a linear function in terms of equipment cost, production targets, availability of standby and safety requirements. The resulting schema for the total maintenance of the equipment, therefore, recommended time-directed maintenance for air compressor, filter beds, chlorinator and the clarifier ; and preventive maintenance for intermediate service pumps, alum saturator, clean water pumps, chlorine discharge line, filter gate valve, delivery valve and aeration blower. Conditioned directed maintenance was recommended for the pipelines. The developed schema was sufficiently justified by a reverse fault analysis. The study concluded that the superiority of risk-based inspection over conventional practices, as a veritable tool in maintenance of mechanical equipment in water treatment plants, is in line with best maintenance standards.

Index Terms— Risk assessment, failure rate, Schema, Critical Index, Severity rating, Reliability, Risk level.

1 Introduction

Water supply is an essential aspect of urban planning and development. Therefore, population and economic growths result in continually increasing demands for water in cities and communities throughout the world, including Nigeria [1]. Water supply and sanitation in Nigeria, though the largest African country and the continent's biggest oil exporter, is characterized by low levels of access to potable water sources and limited access to improved sanitation. In Nigeria, responsibility for water supply is shared between three levels of government - federal, state and local. The Federal Government is in charge of water resources management; state governments have the primary responsibility for urban water supply; and local governments, together with communities, are responsible for rural water supply while the responsibility for sanitation is not clearly defined [2]. Construction of new water supply projects is much more difficult now than in the past due to a number of economic, environmental, institutional, social and political constraints. The Nigeria governments at all levels are, thereby, being forced to place more emphasis on shifting to a greater reliance on management measures that use available resources more efficiently and minimize the need for construction of additional structural improvements.

There is, therefore, always a need to have appropriate technical approach to guarantee that the equipment and all appurtenances are technically viable. It is expected that maintenance cost may be minimized if the equipment in the plant are ranked based on the possible consequence of risk associated with failure of each unit in the over-all health of the plant. This is the underlying principle in Risk-Based Inspection (RBI) technique, which employs ranking of possible risks as a basis to prioritize and manage the efforts of an inspection program. According to [3], there are two extremes of inspection, both undesirable. One extreme is very little inspection replacing pressure equipment and piping when it leaks or fails. The other extreme is inspection of all pressure equipment so often and so thorough that it becomes uneconomical. Several organizations, such as American Petroleum Institute (API), have developed recommended maximum inspection intervals (API-510) but there is no logical method of determining when these maximum intervals could be used. Risk based inspection (RBI) as a method for prioritizing the inspection of plant has therefore received considerable attention over the last few years and methods have been developed, for example by the American Petroleum Institute (API) and by a number of private organizations, particularly in the petrochemical industry [4]. According to [5], risk-based inspection is a method in which assets are identified for inspection based on their associated risks as opposed to a predetermined fixed time interval. It is now widely accepted that traditional time-based approach to planned inspection by a competent person has a number of shortcomings. In particular, the use of fixed intervals between inspections may be too conservative, time-consuming and lacks the freedom to benefit from good operating experience.

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[6] defined risk-based inspection as a technique which is currently being used by some sectors of industry, particularly the Oil and Gas industry, to direct planned plant inspections. It offers the prospect of saving costs resulting from better targeting of resources as it recognizes that there is no point in spending good money and time, for example, on very frequent inspection of something that is very unlikely to fail, or if it did would have little financial or safety consequence.
[7] claimed that Risk-Based Inspection (RBI) is basically to identify inspections for those facilities that pose a higher risk to operate, and thereby summarized the benefits
Developing appropriate Risk-Based Inspection model to determine the likelihood of failure and the consequences of failure will ensure the sustenance of existing water supply facilities if properly applied. This will potentially provide valuable additional information for use in maintenance of equipment used for water supply planning and management.

2 METHODOLOGY

2.1 Sampling of Public Water Treatment Plants

A sample survey approach was considered appropriate for this research work. The research focused on risk based maintenance methodology in the water treatment plants with particular interest in Lagos State Water Corporation, Oyo State Water Corporation (Asejire Dam), and Osun State Water Corporation (Ede Waterworks). These places were chosen because they are public facilities with very high production capacities, and it was also envisaged that there would be adequate accessibility to carry out the research at these locations. The research work was eventually restricted to Lagos State Water Corporation due to non-availability of necessary data and information in other public water treatment plants.

2.2 Data Collection

The required data for this research was collected through primary and secondary sources. The primary source for the collection of the primary data was through the use of structured research questions and face-to-face interviews. The research questionnaires were constructed such that general information about the maintenance breakdowns and the associated maintenance practices were ascertained. The secondary source was the monthly maintenance and breakdown reports over a period of 87 weeks. The factors affecting the quality of risk analysis were identified and analyzed. The applications input and output data were studied to understand their functioning and efficiency. The use of suitable techniques and methodologies, careful investigation during the risk analysis phase, and its detailed and structured results were conducted to make proper risk-based maintenance decisions. Each water treatment plant was considered as unique, and a description of the system was viewed as vital part of the risk analysis. This included the water source, water treatment, and monitoring systems.

2.3 Assessment of the Failure Rates of Mechanical Equipment of the Water Treatment Plants

System selection, data and information collection were conducted in order to assess the failure rates of the mechanical components. A list of the system components was compiled as the first major step while records of all major failures for the past two years were reviewed. Functions of the most critical equipment or subsystem so identified were reviewed and rationalized, and selection of components of the system for the analysis was carried out. The effects of the failure of the main components of the system on productivity and maintenance cost were studied. The factors affecting selection of critical system that was considered during selection and data collection were the available recorded downtime, mean-time between failures, total maintenance cost, mean time to repair, and equipment availability. Functions of the most critical equipment or subsystem so identified were reviewed and rationalized and the selection of component of the system for the analysis was carried out.
Mechanical equipment that were considered included raw water inlet (raw water pumps, alum/pre-lime/copper sulphate injection lines), sedimentation unit (clarified sample pumps, drain valves, poly dispersion pumps, poly helical stirrer), aeration and filtration systems. Operation and maintenance data collection included the equipment history with particular focus on critical equipment based on the collected technical data with emphasis placed on system and functional failures. Based on the equipment records, adequate attention was placed on the vulnerable mechanical equipment that has significant effects on the system. Considered issues included what went wrong, how it went wrong, how it occurred, and consequences of the occurrence when it happened.

2.4 Estimation of probability and consequence of failure factors

A qualitative approach was applied based on the guidelines from various authors. Probabilities and consequences were divided into categories. For probability category, measures as 'rare' and 'frequent' were utilized while consequences were categorized in terms of 'small', 'medium' and 'catastrophic'. The occurrence rating was treated as the numerical probability or likelihood of a particular cause occurring, thereby resulting in the failure mode observed. Based on the generic occurrence rating scale [8] a score occurrence on a scale of 1 – 10 where 1 indicated that it was unlikely to occur and 10 indicated that it was almost certain to occur, was applied. This was tailored to meet the needs of the water treatment plant based on the equipment breakdown reports and the expert judgments of the engineers in charge. The consequence was considered as the severity rating which was the numerical estimate of the severity of the effect of the failure. A sliding scale of 1 – 10 was used where 1 was taken as not significant and 10 as very dangerous, serious, and/or catastrophic. The equipment and their components were prioritized on the basis of their contributions to the system failure. This consequence analysis, therefore, involved assessment of likely consequences if a failure scenario occurred. The generic severity chart was subsequently applied. These categories were subsequently used as the basis for the ranking of likelihood and consequences.

2.5 Risk ranking

Risk was evaluated as a combination of the frequency, or probability, of occurrence and the consequences of a specified undesired event. The process followed a logical progression where system and equipment specific data was superimposed into generic equipment failure data to determine the likelihood of failure, which together determined the risk ranking. A measure of risk level was ascertained by integrating the frequency and consequence factors, and some conclusions were drawn accordingly. For this study, a failure scenario was taken as a description of a series of events which might lead to a system failure. It was taken as either a single event or combination of sequential events; usually a system failure occurs as a result of interacting sequence of events. It was also assumed that the expectation of a scenario did not mean that it would indeed occur but there was a reasonable probability that it would occur. A failure scenario was therefore taken as the basis of the risk study. **Tables 1 and 2** were subsequently utilized, with the risk estimated as the product of the occurrence rating and the effect (severity) rating.

2.6 System root cause failure analysis

Industrial troubleshooting investigations were conducted while critical issues that affected equipment reliability and subsequently contributed to failures were investigated and documented. Root cause analysis was utilized to help identify what, how and why something happened so as to generate recommendations for preventing recurrences in the water treatment plants. Data collection of failures of the identified critical equipment or sub-system, causal factor charting, root cause identification, and recommendation generation and implementation were thus conducted. For the purpose of this research work, the most critical equipment in the water treatment plant was identified and consequently considered for further analysis.

2.7 Failure mode, effects and criticality analysis

A Failure Mode, Effects and Criticality Analysis was conducted to identify potential failures that affected the process performance of the water treatment plants. A screening was performed at the initial stage in order to avoid unnecessary assessments of equipment of low risk. Equipment assigned low consequences and low probability of failure were excluded from the detailed risk assessments in the next phase. Equipment were grouped into hierarchical levels in order to perform the screening. Screening was performed for four categories of failure consequences: impact on production, impact on safety, availability of a standby, and economic consequences i.e. equipment value. Hidden failures, redundancy, and non-operational consequences were not considered in order to address these questions: How can the system conceivably fail? What mechanisms might produce these modes of failure? What could the effects be if failure occurs? How critical is the failure if it occurs? How is the failure detected?

$$(EC) = (30*P + 30*S + 25*A + 15*V)/3 \quad (1)$$

where: EC is Equipment criticality, P is the impact on production factor, S is the impact on safety factor, A is the availability of standby factor and V is the equipment value factor [9]. Hokstad *et al*. (2009) claimed that one possible quantitative measure in the criticality analysis is the risk priority number (RPN), a calculation based on the equation of risk:

$$RPN = C \times O \times D \quad (2)$$

where: C is the consequence of the occurrence of the failure, O is the probability of the occurrence of the failure during a given period and D is an estimate for time needed to detect the failure.

Table 1: Generic Occurrence (Probability) rating Scale

Rating	Description	Potential Failure Rate
10	Very High: Failure is almost inevitable.	More than one occurrence per day or a probability of more than three occurrences in 10 events.
9	High: Failures occur almost as often as not.	One occurrence every three to four days or a probability of three occurrences in 10 events.
8	High: Repeated failures.	One occurrence per week or a probability of 5 occurrences in 100 events.
7	High: Failures occur often.	One occurrence every month or one occurrence in 100 events.
6	Moderately High: Frequent failures.	One occurrence every three months or three occurrences in 1,000 events.
5	Moderate: Occasional failures.	One occurrence every six months to one year or five occurrences in 10,000 events.
4	Moderately Low: Infrequent failures.	One occurrence per year or six occurrences in 100,000 events.
3	Low: Relatively few failures.	One occurrence every one to three years or six occurrences in ten million events.
2	Low: Failures are few and far between.	One occurrence every three to five years or 2 occurrences in one billion events.
1	Remote: Failure is unlikely.	One occurrence in greater than five years or less than two occurrences in one billion events.

Table 2: Generic severity (consequence) rating scale

Rating	Description	Definition (Severity of Effect)
10	Dangerously high	Failure could cause severe injury.
9	Extremely high	Failure would create noncompliance.
8	Very high	Failure renders the unit inoperable or unfit for use.

7	High	Failure causes a high degree of dissatisfaction.
6	Moderate	Failure results in a subsystem or partial malfunction of the product.
5	Low	Failure creates enough of a performance loss.
4	Very Low	Failure can be overcome with modifications to the process or product, but there is minor performance loss.
3	Minor	Failure would create a minor nuisance, but it can be overcome without performance loss.
2	Very Minor	Failure may not be readily apparent, but would have minor effects on the process or product.
1	None	Failure would not be noticeable and would not affect the process or product.

All potential failure modes were listed as much as possible in which with failure modes for all functions considered in any order based on available data. Failure modes were reviewed and rationalized against the expected functions; alongside with failure modes, effects of failure and causes were identified. An effect was considered as the consequence of one failure mode regarding the operation, the function or the status of the water treatment system. For each failure mode, the potential effects of each failure were described while the potential failure causes of each failure were also identified. The criticality assessment was conducted based on domain experts and their judgments, as appropriate percentage weights were allocated to impact on production, impact on safety, availability of standby and impact on cost. This formed the assessment of the significance of the effect on the system operation. The potential causes of that failure mode were identified; these causes were considered to be independent from each other, and determined by the analysis of field failures. Maintenance tasks were established, and appropriate maintenance programmes developed. Equipment assessed to have a low risk of failure was prescribed to have corrective maintenance while rather frequent maintenance programmes were prescribed for equipment assessed to have high risk of failure.

2.8 Criticality analysis for the plant component

Structured expert-elicitation approaches were used to increase the fidelity of the estimates. From the informed knowledge of the maintenance authorities at the plant, therefore, the weight for each of the impact factors is estimated. Accordingly, the safety-related effects was assigned a weight of 40%, production-related effect weighted 40%, cost-related effect weighted 10% while the availability of standby effect was weighted 10% as shown in Table 3.

Table 3: Impact of failures on production, safety, standby, and cost of equipment

Criterion	*Weight	*Levels
Impact on production (P)	40%	(3) – Very important (2) – Important (1) - Normal
Impact on safety (S)	40%	(3) – Very important (2) – Important (1) – Normal

Availability of standby (A)	10%	(3) – Without standby (2) – Without standby and medium availability (1) – With standby and high availability
Equipment value (V)	10%	(3) – High value (2) – Normal (1) – Low value

***Based on engineer's/domain experts' judgment**

Based on the ranking of the criticality of the equipment, the most critical, having the highest risk ranking was selected for further analysis. Root cause failure analysis for the critical equipment in the water Adiyan treatment plant is thus presented. Root cause analysis was therefore employed to examine the process failures, evaluate risk priorities, and to determine the remedial actions to avoid identified problems while failure mode and effect analysis was used to identify the functional failures i.e. the application of the failure mode, effect analysis led to the identification of failure modes.

3 RESULTS AND DISCUSSION

Based on the ranking of the criticality of the equipment, the most critical, having the highest risk ranking was selected for further analysis. Root cause failure analysis for the critical equipment in the water Adiyan treatment plant is thus presented. Root cause analysis was therefore employed to examine the process failures, evaluate risk priorities, and to determine the remedial actions to avoid identified problems while failure mode and effect analysis was used to identify the functional failures i.e. the application of the failure mode, effect analysis led to the identification of failure modes.

3.1 Inventory of mechanical equipment in public water treatment plant

Based on available records at Adiyan water treatment plant, being the highest design capacity and the most active plant at time of study, the following equipment and facilities were identified.

(i) Raw water inlet: 1 inlet chamber tank, 2 flash mixers, 6 clarifier tanks, 1 alum injection line, 1 pre-lime injection line, 1 copper sulphate injection line, 2 raw water sampling pumps, and 1 raw water flow meter.

(ii) Aeration system: 2 aeration tanks, 2 air distribution pipes, and 3 aeration blowers.

(iii) Filtration stage: 6 filter beds. Sedimentation/clarification unit: 6 clarifiers, 2 clarified sample pumps, 12 clarifier vacuum fans, 6 clarifier control panels, 6 clarifier tank float switches, 1 float indicator, 6 clarifier solenoid valves, 18 pneumatic solenoid drain valves, and 18 manual solenoid drain valve.

(iv) Clear water tank with 7 pumps; these are located at the Intermediate Pump Station (IPS).

3.2 Failure Rates of Mechanical Equipment of the Selected Water Treatment Plants

The rate of failure of each mechanical equipment was extracted from the available plant maintenance and breakdown reports of Adiyan waterworks from May 2014 to December 2015. It was shown from the records that pumps have the highest rates of breakdown as shown in Table 4. Some pumps were completely isolated due to breakdowns that required long lead items to carry out the repairs. Consequently, clean water pumps and intermediate service pumps have the very high rates. However, the intermediate service pumps have higher rates than the clean water pumps. Records of pump performance and the associated breakdowns were not adequately kept per unit in most cases.

The plant maintenance and breakdowns were recorded only for the process air compressor, alum saturator, filter beds, clean water pumps located at intermediate station service pumps, chlorine discharge line, pipeline, clarifier, filter gate valve, delivery valve and aeration blower. Chlorine discharge line had the least recorded downtime of 2 over a period of 87 weeks, averaging 2.3% downtime per week, while the clear water pumps located at the Intermediate Pump Station (IPS) had a downtime of 83 in 87 weeks to average 95% downtime per week as shown in Table 12. This clearly manifested that pumps constituted a major critical concern to water treatment plants. Associated problems with the intermediate service pump that led to downtime included excessive vibration, excessive water leakage, tripping on overload and other electrical problems, faulty switches, faulty bearing and coupling, worn-out wear rings, misalignment and excessive noise. Causes of excessive noise and vibration, as confirmed from the technical personnel, included unbalanced rotating components, damaged impeller and non-concentric shaft sleeves, warped shaft, pump and driver misalignment, pipe strain, rubbing parts, worn bearings and damaged internal parts.

Associated problems with alum saturator, having a downtime of 21 (estimated 24% rate of failure per week) within this study period, were mainly due to clogged strainer and inappropriate chemical levels and dosing rates; these were identified as repeat problems. Clogging was the major problem with the filter beds which had a downtime of 21 and estimated 24% of failure rate per week. It took a very long time to repair the filter beds due to non-availability of necessary replacement parts. Breakdown was predominantly due to heavy corrosion of the internal parts. Process air compressor and the aeration blower had a downtime of 21 (24% failure rate per week) and 4 (5% failure rate per week) respectively.

Table 4: Summary of Plant Maintenance and Breakdown Records – Adiyan waterworks

Item	Breakdowns in 87 weeks	% Estimated Rate of failure/week	Associated problems
Clean water pumps located at the Intermediate Pump Station (IPS)	83	95	Excessive vibration; excessive water leakage; tripping on overload; electrical problems; faulty switches; faulty bearing and coupling; worn-out wear rings; misalignment; excessive vibrations; electrical problems.
Process Air Compressor	21	24	Not defined.
Alum saturator	21	24	Clogged strainer; inappropriate chemical level/dosing rates.
Clarifier	12	14	Dislodging of slurry fluid in clarifiers.
Filter beds	12	14	Clogging.
Filter gate valve	7	8	Leakages.
Delivery valve	4	5	Leakages/clogging.
Aeration blower	4	5	Not defined.
Pipeline	3	3.4	Severe leakages and blocked drain lines at Intermediate Pump Station.
Chlorine discharge line	2	2.3	Leakages; clogging.

Source: Adiyan waterworks monthly maintenance and operations reports

Applying Equation (1) and Table 3, Table 5 was subsequently constructed while the maintenance schedule for the components of the intermediate pump is as shown in Table 6. Failure mode and effect analysis was used to establish the functional failures as the application of the failure mode, effect analysis led to the identification of failure modes. Possible actions to reduce the consequence or the frequency of failure mode were considered as risk reduction options upon which maintenance programmes were specified for the identified critical equipment. Because of the high rate of failure and severity of the intermediate service station pump (identified as the critical equipment during this research study), the criticality of the pump was estimated to be very high. It is thereby deduced from above that condition-based maintenance is applied to the pump. This approach was thus used to recommend the maintenance task and maintenance plan for the water treatment plant.

Table 5: Criticality analysis for the intermediate service station pump

Equipment	**Failure mode**	**Failure cause**	**Criticality Analysis**				**Criticality index**	**Grp**
			Safety	**Production**	**Cost**	**Availability**		
Intermediate water station pump (Clean water pump)	High bearing temp.	Bent shaft	3	3	1	3	2.8	A
		Worn bearing	3	3	2	3	2.9	A
		No lubrication	3	3	2	2	2.8	A
		Improper installation of bearing	3	3	2	2	2.8	A
	Pump casing overheats	Misalignment of motor	3	3	3	1	2.8	A
		Shaft sleeve worn out	3	3	3	2	2.9	A
	Low flow	Impeller damaged	3	3	3	3	3.0	A

Table 6: Maintenance schedule for the intermediate service station pump components.

Equipment	Failure mode	Failure cause	Group	Task	Description	Frequency
Intermediate service pump	Bearing runs hot	Bent shaft	A	CD	Check shaft alignment & align/replace as required.	Weekly
		Worn bearing	A	CD	Check for bearing temp., and replace bearing as required.	Monthly
		No/poor lubrication	A	TD	Conduct adequate lubrication	Daily; change oil in 3 months.
		Improper bearing installation	A	CD	Check unusual noise, vibration & bearing temperature; Check cooling system.	Weekly
	Pump casing overheats	Misalignment of motor	A	CD	Check for unusual noise, vibration and bearing temp.; replace as required.	Check foundation and hold down bolts for tightness in 3 months.
		Worn out shaft sleeve	A	CD	Check shaft sleeve conditions and alignment; replace as required.	Monthly
	Low flow	Damaged impeller	A	CD	Check impeller conditions and replace as required.	Check in 3 months.

3.3 Validity of the Developed Schema.

For this research work, failure to pump water with the centrifugal pumps located at the intermediate service pump station was identified as the undesired "top event" in the application of the fault tree analysis. Two pumps were identified for analysis at this pump station and it was expected that one unit worked to meet up with the process demand i.e. it was sufficient that one unit functioned in order to avoid the undesired event.

To create the fault tree, three possible events that caused the top event to occur were identified. These were:

(i) No input, that is, the pumps did not receive water.

(ii) None of the pumps was working.

(i) Motors of pumps fail (including power failure).

The second event was subsequently broken down into 2; these are:

(i) Pump 1 failed to pump water.

(ii) Pump 2 failed to pump water.

At this stage, no further breakdown of the fault tree was possible; at the bottom of the fault tree, four basic events were identified as:

(i) NI = No input to pumps.

(ii) P1 = Pump 1 fails.

(iii) P2 = Pimp 2 fails.

(iv) CP = Common motor/ power failure, causing both pumps to fail.

For the pump to fail to function, it was sufficient that NI or CP event occurred alone. Finally, the top event, that is, failure to pump water occurred when both P1 and P2 occurred. Three (minimal) cut sets were subsequently identified as S1 = {NI}, S2 = {CP}, and S3 = {P1,P2}.

The probability that top event will occur, that is, pump not working was thus assessed as:

$$P(\text{top event}) = P(NI) + P(CP) + P(P1) \times P(P2) \quad (3)$$

This final equation, thus, satisfies the law of addition of probabilities.

4 CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSIONS

The study evaluated failure rates of selected public water treatment plants and the observed range is 2.3% to 95%, the maximum being the intermediate station service pump due to high criticality index and frequency of failure with the minimum being the chlorine discharge line.

The study also shows that the overall performance of the water treatment plants depends serially on the raw water pumps, filters, intermediate pumps and cold water station, and subsequently in series to the parallel arrangement of sub-units of clarifiers and aeration tanks.

The study established time-directed maintenance for air compressor, filter beds, chlorinator, clarifier, and preventive maintenance for alum saturator, clean water pumps, chlorine discharge line, filter gate valve, delivery valve and aeration blower, and condition-directed maintenance for the pipelines.

It was concluded that the developed schema satisfies the law of addition of probabilities in plant maintenance scheduling.

4.2 RECOMMENDATIONS

Risk-based maintenance appears to be superior to other risk analysis approaches which are deficient in uncertainty and system analysis.

(i) RBM is recommended for stepwise applications in water treatment plants and can be extended to any maintenance facility to guide where and when to perform maintenance.

(ii) In a further study, the model developed may be developed into a user=friendly software.

(iii) Adequate documentation of maintenance practices should be put in place; poor or inadequate documentation constituted a major hindrance to the development of maintenance culture.

(iv) Adequate equipment monitoring forms should be put in place and fully utilized. Correct maintenance practices should be enhanced on continuous and regular basis. As such, checklists and equipment monitoring forms should be updated time to time as the machine age and the contents therein followed strictly.

(v) Equipment should be replaced at the optimum time. Management should have pre-knowledge of the lifespan of machines, equipment, and/or machine parts and execute

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