Productive Maintenance's Autonomous Maintenance in Achieving Effectiveness: Case Study

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Abstract

The research study investigated the prospects of using Autonomous Maintenance to improve maintenance effectiveness advantage for the thermal power plants. Through plant audits, critical equipment was identified using Nowlan and Heap's risk analysis method and confirmed using the criticality function (SAQM). The identified critical equipment were boilers, turbines, pumps, condensers, supeheaters, grate and belts. Autonomous Maintenance implementation procedures were developed for the plant and, the cause and effects of failure of each critical component were analysed using fishbone diagrams. Autonomous Maintenance checklists for each critical equipment were developed basing on the implementation strategy. The maintenance database checklists, KPI data and software were used as the end user interface for accessing the procedures and inputing KPI data in to the system for storage. The implementation were based on continous improvement as a cycle incorporating real time monitoring system in the plant.

Keywords: Total productive Maintenance, AutonomousMaintenance, Maintenance Effectiveness, Advantage, Key Performance Indicators

1. Introduction

Over the years, manufacturing organizations have experienced an unprecedented degree of change including drastic change in management approaches, increasing complexities in products and process technologies, inflated market demands and customer expectations, and unpredictable supplier attitude(Ahuja & Khamba, 2008). In number of organizations, often production and manufacturing systems operate below full capacity, leading to low productivity and high costs of operating and maintaining machinery in factories. Local and global competition propelled by highly dynamic markets and rapidly changing business environment, has resulted in increased customer demands of high quality and affordable products and services from the manufacturing organizations (Blanchard, 2002). The rapidly increasing competition calls for companies to increase performance through focus on cost cutting, increasing productivity levels, high quality and state of the art product features for customer satisfaction, guaranteed profitability and survival of the organization.

2. Background

Thermal power plant was mostly implementing ineffective maintenance strategies comprising of crisis maintenance and preventive maintenance resulting in high equipment breakdowns, high maintenance costs and unplanned equipment downtime, under-utilization and damage of equipment, thereby failing to reach company energy generation targets. This is due to a number of reasons which include old age of equipment, harsh economic conditions, hence organizations cannot move to modern maintenance strategies as they have high startup costs, shortage of foreign currency hence organizations cannot import spare parts. The main equipment within the organization is at least sixty-five years old whilst its designed lifetime is thirty years. Therefore, old age is one of the major reasons why the organization implement crisis maintenance. Also, due to harsh economic environment and shortage of foreign currency, the organization could not adopt modern maintenance strategies which are expensive to setup and also could not procure spare parts in time thereby opting for run to failure on most of the equipment. However, because of the adverse effects of run to failure maintenance, most of the critical equipment at the power plant has failed and has been decommissioned leading to reduction in generating capacity from an installed Capacity of 120 MW to only 20MW.

3. Thermal Power Plant maintenance review

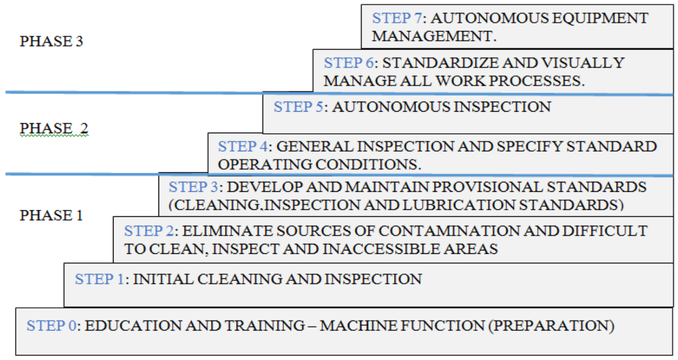
The power generation industry constitute part of the critical, most important and vital industries in the modern world as our day to day lives now depends on energy use. For critical industries like power generation, plants are expected to have an availability of at least 90% and are required to operate at the highest possible efficiency to meet the demand. Over the past years, maintenance has changed, perhaps more than any other management discipline.

Total Productive Maintenance is a modern proactive maintenance strategy focused on maintaining and improving the integrity of production facilities and quality systems through the machines, equipment, processes, and employees that add business value to an organization. TPM is a top down bottom up maintenance strategy which involves all employees at all levels in the organization from the shop floor workers up to the top management (Mugwindiri, 2017). The goal of TPM is to increase the Overall Equipment Effectiveness (OEE) of plant equipment through addressing the causes for accelerated deterioration while creating the correct environment between operators and equipment to create operator equipment ownership. The pillar approach is a way of managing change and a rigorous methodology to ensure sustainable development for the organization(Venkatesh, 2007). According to (Ahuja & Kumar, 2009) implementation of TPM's eight pillars begins with the 5'S philosophy which focuses on cleaning and organizing the workplace. Problems cannot be clearly seen it the workplace is dirty and unorganized therefore 5'S helps to uncover hidden problems making them visible which is the first step for improvement. The 5'S philosophy is summarized in the Table 1 below.

Table 1 Meaning of 5's (Mugwindiri, 2017)

Japaneese Word	**English Translation.**
Seiri	Sort out the work place.
Seiton	Organize (Tidiness of the work place).
Seiso	Cleanliness.
Seiketsu	Standardization.
Shitsuke	Discipline.

Autonomous maintenance is not a one-time implementation maintenance strategy. To maximize the benefits of AM, it is implemented in stages with each stage being implemented after the preceding stages have been fully implemented. The implementation procedure comprises of seven steps which are grouped into three phases.



The steps must be holistically implemented from step 0 to step 7. Steps in the same phase can be simultaneously implemented as the main AM procedure must be implemented in the three phases listed above. In implementation of Autonomous maintenance in an organization, management should ensure that each phase has been successfully implemented and no step has been skipped before moving to the next phase. To ensure this, AM implementation involves a Plan DO Act Check (PDCA) cycle as a monitoring tool to the implementation of the steps and phases.
After a successful implementation of AM, the processes must continue and AM must be sustained until it is a culture of the whole organization. If this does not happen, the organization can revert to previous practices even if AM was successfully implemented. Therefore, to sustain AM within an organization, there must be active leadership for AM initiative supported by management for the organization.
According to (Mobley, 2002), the benchmark used for TPM programs is Overall Equipment Effectiveness (OEE). There are other key performance indicators like quality, delivery performance, safety, productivity and cost but these are all encompassed in OEE. OEE is a total measure of performance that relates the availability of the process to productivity and quality (Morow, 2000). These KPI's world maintenance are summarized as given in Table 2.

Table 2 World class maintenance KPIs

Maintenance KPI	**Acceptable Levels**
Planned maintenance work	>90%.
Breakdown/Crisis Work	< 3%.
Maintenance Schedule Compliance	> 90%.
Written work orders	>98%.
Maintenance overtime	<5%.
Overall Equipment Effectiveness	>80%.
Occupancy of maintenance technicians	>95%.
Maintenance Cost	< 2.5% of ERC (Estimated Replacement Cost)

4. Methodology

The researchers had to make industrial attachment to the thermal power plant to collect row practical data for analysis and evaluation.The methods used in data collection included interviews, questionnaires and observations by the researchers during the period of attachment to the company. The researchers carried out a detailed case study of the plant so as to understand the company's line of business, vision, goals and detailed information on the current maintenance strategies being implemented. Critical equipment was also identified using balanced score card and criticality analysis method and equipment data was obtained from the case study. The collected data was then analyzed using various software.

5. Case study

Thermal Power Plant is located in the southern part of the country. The coal fired thermal power plant was commissioned between 1947 and 1957 as an undertaking by the local government authority to cater for the electrical needs of various industries which were located in the town. Upon commission between 1947 and 1957, the plant had an installed capacity of 120 MW which was later changed after a refurbishment exercise on the ageing plant gave it a new lease of life with an installed capacity of 90MW. At full capacity, the plant operated ten stoker fired chain grate boilers and five turbine machine assemblies but however, because of old age and failures, the company now runs four stoker fired chain grate boilers and one turbine machine assembly. Currently the plant generates an average of 18MW and is connected directly to the national grid through a 11kV and 33kV system.

Figure 1 Aerial view of Thermal Power Plant (Photo by Mutenhabundo 2017)

The plant has an ISO 9001: 2015 accreditation for its quality management system, ISO 14001: 2015 accreditation for its environment management system and OHSAHS 18001: 2007 accreditation for its health and safety management system. It is the only power station which is certified in all the three standards which are listed in the IMS policy. The summary of the equipment is given in Table 3.

Table 3 Table of equipment operated and its current status (2018)

Plant Equipment	**Design Capacity (MW)**	**Current Capacity (MW)**	**Patent Date**
Boiler 1	7.5	Decommissioned	Yarrow Glasgow
Boiler 2	7.5	Decommissioned	Yarrow Glasgow
Boiler 3	7.5	Decommissioned	Yarrow Glasgow
Boiler 4	7.5	Decommissioned	Yarrow Glasgow
Boiler 5	15	Decommissioned	Yarrow Glasgow
Boiler 6	15	7.5	Yarrow Glasgow
Boiler 7	15	7.5	Yarrow Glasgow
Boiler 8	15	Decommissioned	Yarrow Glasgow
Boiler 9	15	7.5	Yarrow Glasgow
Boiler 10	15	7.5	Yarrow Glasgow
Turbo-Generator 1	15	Decommissioned	British Thomson Houston Patents
Turbo-Generator 2	15	Decommissioned	British Thomson Houston Patents
Turbo-Generator 3	30	Out of service due to failure (rotor earth fault).	Parsons Patent 1944 South African Patent 1940
Turbo-Generator 4	30	30	Parsons Patent 1944 South African Patent 1940
-Turbo-Generator 5	30	RLA	Parsons Patent 1944 South African Patent 1940

The organization has a vision move towards provision of clean and sustainable energy generation. Its organizational structure defines the responsibilities and official reporting lines of all the employees. This enhances team work and enhanced decision making, through interaction of employees from different departments and expertise leading to achievement of organizational goals. The organizational structure also enables the employees to understand their respective duties, abilities and limitations through a clear understanding of who to officially report to in different situations which enhances proper conduct and respect amongst employees and improved operational efficiency.The maintenance strategies being implemented at plant still resulted in high failure frequency of equipment and low plant availability. The condition of some of the equipment is shown in the Table 4.

Table 4 Equipment and its condition (2017).

Plant status	**Condition**
Steam Leakage	Frequent
Water Leakage	Frequent

Chemical Leakage	Low
Grate failure	Frequent
Condition of Flooring	Poor
General Cleanliness	Poor
Boiler tube failure (leakage)	Frequent
Condenser tube failure (leakage)	Frequent
Super heater tube failure	Frequent
Fan failure	Frequent
Pump failure	Frequent

Equipment criticality was determined based on four factors which are safety, availability, quality and maintainability. The effects of failure of each equipmenton these four factors are analyzed and used to calculate criticality of the particular equipment. Each function is considered on how its failure affects the equipment and given a score from the table of scores based on its effects.

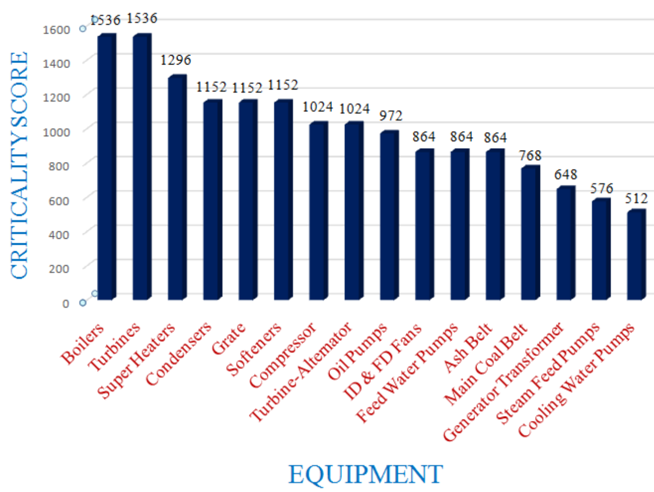


Figure 2 Equipment criticality score

The identified critical equipment is shown in the graph (Figure 2) with the level of criticality. The focus of the study will be mainly on the maintenance effectiveness of the selected critical equipment. This is because the equipment has the highest criticality scores, they have more failure modes and they are the most important equipment at the plant.

6. Research findings

The researchers conducted an in depth analysis of previous maintenance data from the calendar year 2017 going backwards. The qualitative and quantitative data to be analyzed was obtained from the company's maintenance department. The actual operating data will be compared to the station targets to draw a conclusion of how the actual performance deviates from the targeted one and hence conclude on the effectiveness of maintenance strategies.

Overall equipment effectiveness:Figure 3 shows OEE KPI performance from the previous data collected.

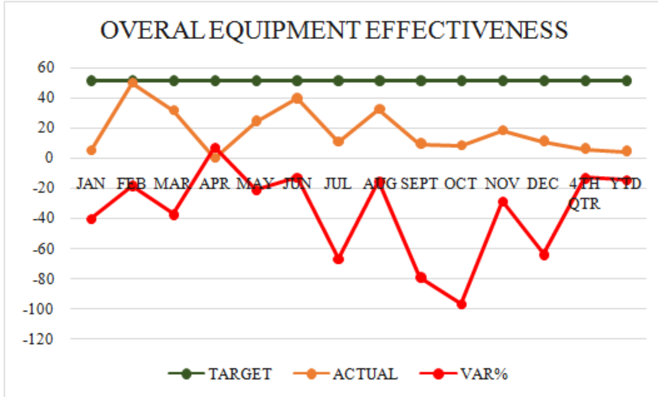


Figure 3 Graph of overall equipment effectiveness

Overall equipment effectiveness is a strong performance indicator on the effectiveness of a particular maintenance strategy. The target OEE for the organization was very low as a result of high equipment breakdowns. The actual OEE was very low below the target OEE, which shows that equipment operates way below the targets because of poor maintenance effectiveness. The variance of target and actual OEE was always negative except in May where a high OEE was achieved as a result of a major pre-winter maintenance done in March. The lowest OEE was in October which was caused by continuous operation of equipment with minimum maintenance during the winter period.

Thermal efficiency:The efficiency of a thermal power plant depends on equipment effectiveness and proper maintenance. Poorly maintained equipment operated below its rated efficiency due to functionality loses. From the graph of plant efficiency, the equipment was way below the rated efficiency and with a negative variance except in May. The high efficiency in May was obtained as a result of major maintenance during the pre-winter shutdown in April. Therefore, from the graph, it could be concluded that the maintenance was ineffective as shown by low plant efficiencies throughout the year.

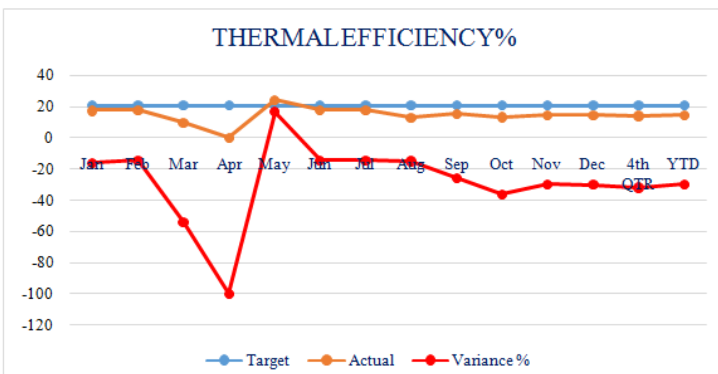


Figure 4 Graph of thermal efficiency

Plant availability: Maintenance directly affected plant availability. Due to high frequency of equipment failure due to poor maintenance, the plant had a very low plant availability which was way below the target availability.

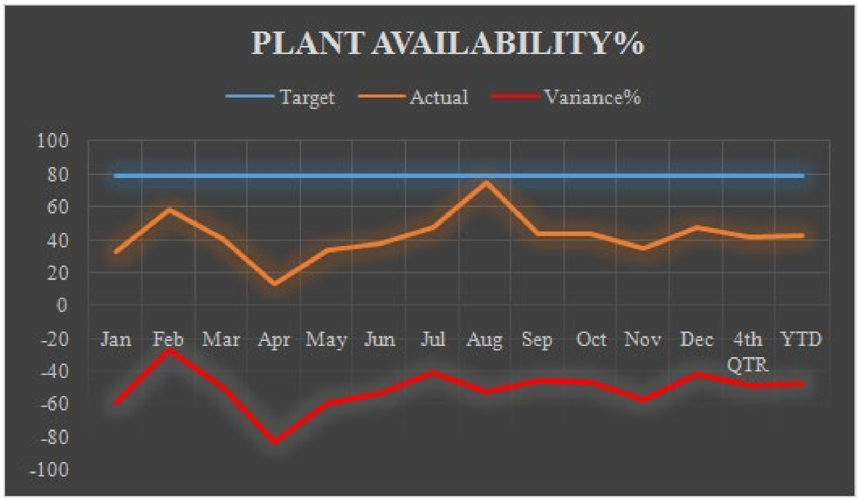


Figure 5 Graph of plant availability.

Plant availability: A plant with low availability is unreliable. The Thermal plant had avery poor plant reliability due to frequent equipment failures and low plant efficiencies as shown by the graph.

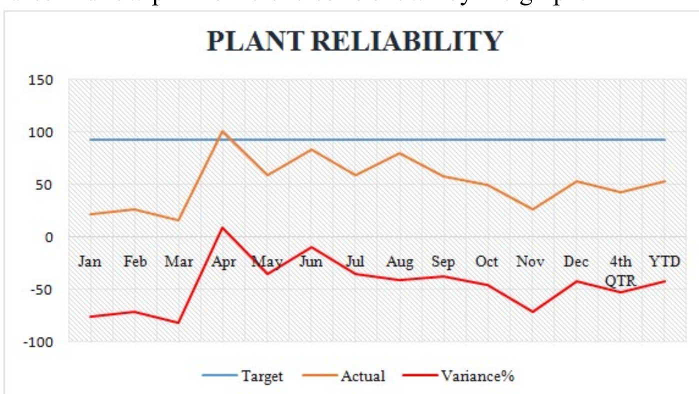


Figure 6 Graph of plant reliability

Planned outages rates: Due to poor maintenance strategies, planned outages usually take long time than planned as a result of unavailability of spares, high equipment breakdowns and poor worker utilization.

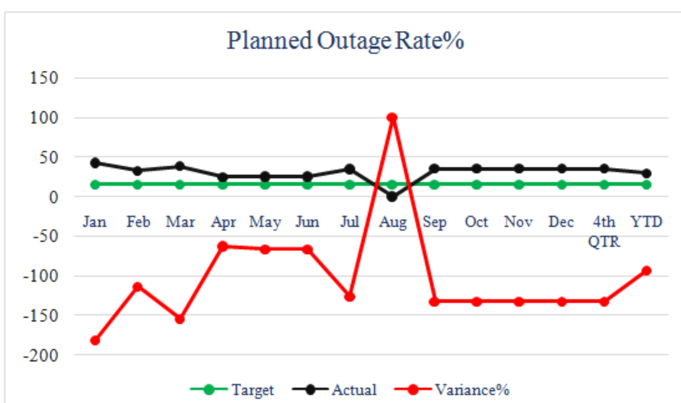


Figure 7 Graph of outage rates

Due to poor maintenance strategies, planned outages usually take long time than planned as a result of unavailability of spares, high equipment breakdowns and poor worker utilization.

Forced outage rates: Forced outage rates are a direct indication of the company's maintenance effectiveness. The plant had high forced outage rates as a result of unplanned equipment failures due to poor maintenance. This is shown in Figure 8 with a high variation of actual to target forced outage rates. The deviation was extremely negative which shows a greater deviation from the target rates. Forced outage was mainly as a result of equipment failure hence this showed high equipment failure rates, low plant availability and reliability which all are characteristic of crisis maintenance which is a poor maintenance strategy.

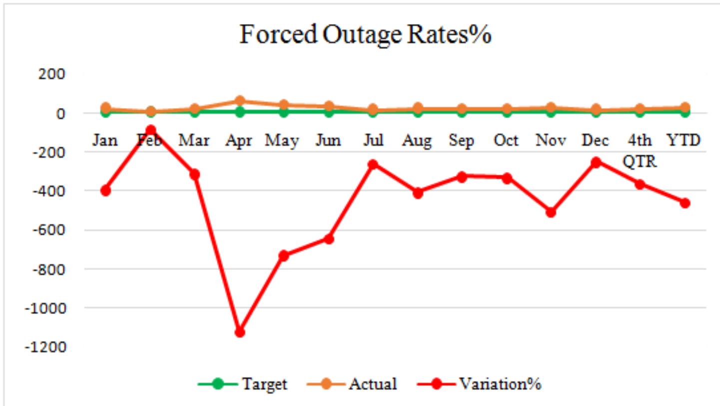


Figure 8 Graph of forced outage rates

From the performance graphs, it could be concluded that the operating conditions for the plant have deteriorated from the year 2016 to 2017. Deviations in variations have increased which shows that the maintenance strategy being implemented was poor as there was no improvement on plant performance. From the maintenance data obtained from the company, there is a strong evidence that the maintenance at the plant is very poor as shown by the performance indicators analysed. The targeted overall equipment effectiveness is very low, 51.52%, and the actual OEE deviates with large negative values from the targeted one which shows the ineffectiveness of maintenance.

7. Analysis of results

Of the managers who participated in the survey, only 58% had a clear understanding of autonomous maintenance and the rest gave responses that it is a new strategy. All the managers at the plant appreciated the importance of maintenance for sustainable growth. The managers fully understood the importance of maintenance in improving KPI's and the overall quality of the products, and proper functioning of the equipment. However, the mainly implemented maintenance strategy is breakdown maintenance and preventive maintenance which was mentioned by all the managers with only 60% of the managers mentioning reliability centered maintenance. It could be concluded that there is need to implement Autonomous Maintenance to improve maintenance effectiveness.From the general AM procedure, the specific maintenance procedure for AM activities on critical equipment was designed.

7.1 Boiler plants

At the thermal power plant, boiler failure rate was frequent and this has been mainly due to several factors such as old age, tube leaks, grate shaft and bearing failure, super heater drum failure, feed and extraction pump failure and failure of steam control valves.

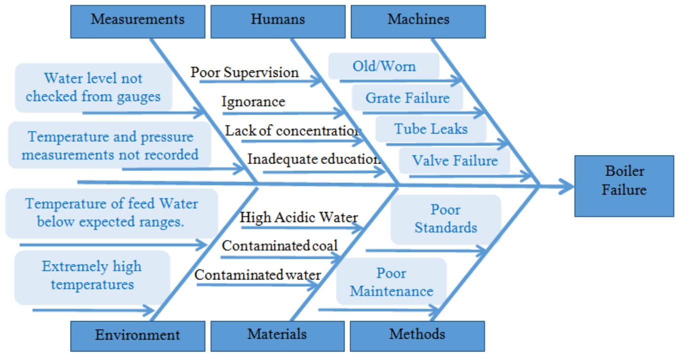


Figure 9 Fishbone diagram for boilers

The AM implementation plan was formulated and divided into three levels and a daily checklist for the boiler plant. Boiler operators had to be trained on need for basic inspection, cleaning, lubricating and contamination control. They have also to be taken through the equipment and its auxiliaries, its functions, failures and the possible causes of failure. Operators must be able to carry out routine maintenance works which include repairs of minor defects. This reduces unnecessary downtimes of waiting for maintenance personnel to fix such minor defects such as tightening screws. For routine maintenance works, the maintenance checklist for boiler plant to be used by operators is outlined below.

Table 5 Boiler plant checklist

DESCRIPTION	COMMENTS	MAINTENANCE FREQUENCY			
		DLY	WKLY	MNTLY	ANLY
Check water level control	Check if boiler has sufficient water and record value	✓			
Check temperature and pressure regulators	Must be within the allowable range.	✓			
Check chain grate	Check if rotating properly and if louvers are well aligned	✓			
Check grate shaft and bearings	Check for wear on shaft and proper lubrication on bearings	✓			
Check all safety relief valves, boiler and steam control valves	No leaks	✓			
Check super heater and main steam drums	No pressure drop and leaks.	✓			
Check boiler feed and extraction pumps.	Must have sufficient head	✓			
Check blowdown and feed water pH	Determine if blowdown is sufficient to avoid solids build up and pH is sufficient to avoid corrosion.	✓			
Check combustion chamber and flue gas pass	Check flame characteristics and flame failure.	✓			
Check all belts and packing glands	Belts must have proper tension and not worn out. No leaks on glands	✓			
Check economiser leaks and feed water temperature	No pressure drop and feed water must be at a higher temperature	✓			
Check safety shut off device	Must move freely	✓			
Check temperature and pressure gauges	Must be well calibrated and within range	✓			
Check flue gas temperature and composition	Must be within regulatory range.	✓			
Visually inspect the whole boiler system.	Check for ash, water, air and steam leaks.	✓			
Check for ash belts	Inspect tightness and slippage	✓			
Check boiler insulation and refractory	Well insulated and intact	✓			
Check coal supply system and ash passages	Passage must be free of foreign objects.		✓		
Check air circulation fans	I.D, F.D and booster fans		✓		
Check grate gearbox	Oil levels must be within range, no leaks and speed selectors functioning		✓		
Check under grate dampers	Must freely open and close and no air leaks		✓		
Check generator tube leaks	Must be dry		✓		
Check all gaskets	Must provide tight sealing		✓		
N.B: BECAUSE OF AGE OF BOILER PLANTS, OPERATOR MAINTENANCE SCHEDULES ARE REDUCED TO DAILY AND WEEKLY ONLY. MONTHLY AND ANNUALY MAINTENANCE WORKS ARE PERFOMED BY MAINTENANCE DEPARTMENT.					

7.2 Turbines

Together with boilers, turbines were determined to be the most critical equipment in the plant. Turbine failure would be very catastrophic as they are very expensive and it leads to total shut down of the plant and failure of other equipment like turbo alternator and transformers. AM is a key maintenance strategy to implement so as to ensure that the turbine does not fail.

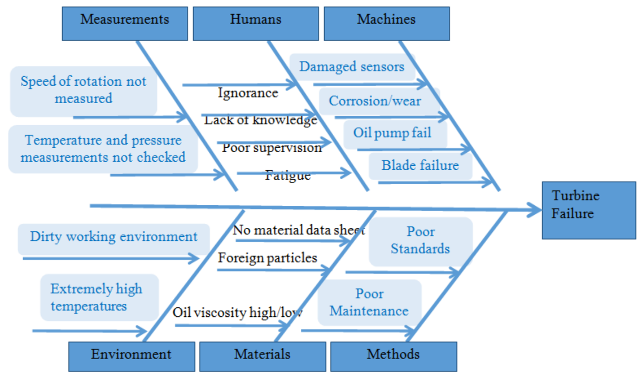


Figure 10 Fishbone diagram for steam turbines

As steam turbines are intact and cannot be frequently opened, inspection and condition monitoring from sensors gives the best way of monitoring the turbines. For turbines, operators must understand remote monitoring and inspection for analyzing turbine condition during operation without stopping or opening it. Operators are also taught to read and interpret graphs from control boards which show turbine conditions. The maintenance checklist for the turbine is given by Table 6.

Table 6 Steam turbine checklist

DESCRIPTION	COMMENTS	MAINTENANCE FREQUENCY	
		DAILY	WEEKLY
Monitor bearing housing oil levels	Must be above the low mark	✓	
Monitor bearing metal temperatures	Must be in range of material.	✓	
Monitor bearing housing vibration levels	Must not exceed specified vibration from manual	✓	
Measure steam flow rates	Must be sufficient to avoid condensation of steam	✓	
Measure inlet and outlet steam pressure and temperature	Control using governors to match required power output	✓	
Measure speed of rotation	Must be below critical speed	✓	
Measure load, current, voltage an load	Avoid overloads greater that the specified maximum overload	✓	
Walk around to inspect for unusual noise and leaks	No leaks and unusual sounds.	✓	
Check lubrication, seal and control oil pressure and temperatures	Viscosity of oil and lubrication must not be out of range and oil must reach the bearings	✓	
Check for steam leaks, pressure and temperature drops from sensors	Constant pressure areas must maintain constant pressures and no steam leaks	✓	
Check for all turbine valves	Must freely open and close	✓	
Measure and record power output from the turbine	Analyze the data to calculate efficiency	✓	
Measure and record inlet and outlet steam pressure	To check for pressure drops	✓	
Check all sensors and meters from the control board	Must properly function and within calibrated range	✓	
Check rotor alignment sensors	Rotor must always be aligned at the center		✓
Check turbine governing systems	Must freely open and close and intact		✓
Check air and lubrication oil filters	Replace when dirty and clogged		✓
Check generator ventilation openings	Clean when dirty and clogged		✓
Check oil pumps and oil circuit	Oil must freely circulate. No blockage		✓

7.3 Condensers

Condensers convert steam to liquid water after exiting the turbine. They are also critical equipment as they greatly improve the efficiency of the cycle and failure of condensers result in total shutdown of the plant and loss in production time. The major problemassociated with condensers is condenser tube leak and blockage of condenser tubes from clogging. This occurs frequently as a result of old age and presence of dissolved substances in cooling water. The fishbone diagram for the condenser is given below in Figure 11.

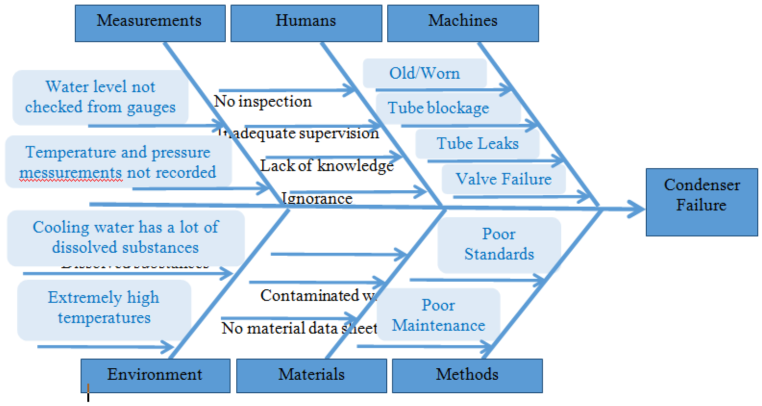


Figure 11 Fishbone diagram for steam condensers

After undergoing the general AM implementation procedure and condenser operators could follow the steps outlined in the checklist below to carry out autonomous maintenance work on the condenser. Due of old age and high failure frequency of the equipment, autonomous maintenance works are scheduled for daily and weekly intervals.

Table 7 Steam condenser checklist

DESCRIPTION	COMMENTS	MAINTENANCE FREQUENCY	
		DAILY	WEEKLY
Check outdoor condensing unit	Check for dirty, cracks, leaks and corrosion.	✓	
Check for visible steam and water leaks	Check for water droplets and corrosion on the condenser.	✓	
Check suction and discharge pressure	Pressure readings must be within operating ranges	✓	
Check inlet and exit temperature of fluid.	There must be a temperature drop between the fluids.	✓	
Inspect safety controls	Must be properly working.	✓	
Inspect fluid flow rates through the condenser	Check fouling and tube leaks from flow rates	✓	
Check all control metres from the switch board.	Must be properly functioning and in the calibrated ranges	✓	
Check for steam and water side tubes.	Check for leaks and blockage	✓	
Move around condenser and listen for abnormal sounds	Listen for fluid leaks and blow off.	✓	
Visually inspect the condenser circuit	Check for leaks, blows and corrosion of equipment	✓	
Check condenser filters and steam chest	Must be clean and allowing continuous flow	✓	
Check condenser control valve and meters	Check for leaks and proper calibration.	✓	
Check inlet and exit temperature of fluid to the air coolers	There must be a notable temperature drop from the fluid	✓	
Inspect condensate drain line p-trap	Condensate pressure and flow must be constant		✓
Check current and voltage to the equipment	Check for overcurrent		✓
Inspect fluid flow lines	Check for leaks and pressure build in the lines		✓
Check air cooler and inspect air flow circuit	Check for air leaks and high backpressure		✓
Check chemical composition of condensate	If contaminated, it shows sign of tube leak, erosion or corrosion of tubes.		✓
Check condenser vibration sensors.	Must be within permissible range		✓
Check for thermal stresses on condenser coils	Tubes must no shrink .		✓

7.4 Pumps

Pumps constitute a greater proportion of equipment at the thermal power station. They are critical to the operation as many processes are driven by pumps. Failure of major pumps like boiler feed and extraction pumps, cooling water pumps, oil pump and sludge pump can be catastrophic and can lead to a major downtime and pollution of the environment. These have been mainly caused by factors such as bearing failure, coupling failure, shaft misalignment, worn out impellers and contamination of lubrication. From the Figure 12 below, a checklist for pumps can be developed so as to mitigate the causes and effects of pump failure and to achieve a prolonged efficient pump operation. The checklist outlines the steps which must be carried out by operators on daily and weekly basis so as to identify problems earlier and solve them before failure occurs.

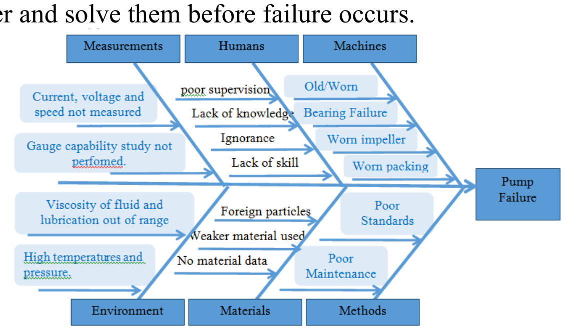


Figure 12 Fishbone for pumps

Table 8 Pumps check list

DESCRIPTION	COMMENTS	MAINTENANCE FREQUENCY	
		DAILY	WEEKLY
Inspect pump inlet filters	Check for dirty and clean them	✓	
Check oil level and condition of oil	Must be consistent and check for water and other contamination	✓	
Check pump for oil leaks	Check on bearings and crankcase	✓	
Check pump for water leaks	Water must not mix with oil in crankcase	✓	
Inspect valve cap O-rings and sleeves	Check if they are intact and not allowing water to pass	✓	
Inspect packing assembly and mechanical seals	Must be intact around shaft and allow slight leakage	✓	
Check fluid level in engine	Refer to manufactures manual for required fluid levels	✓	
Inspect for abnormal sounds from the pump	Noisy operation signals failure of a particular component	✓	
Check for bearing lubrication	Bearing must be continually lubricated during and after operation	✓	
Inspect current and voltage to the motor	Must not exceed specified limits on the name plate	✓	
Inspect bearing and bearing housing	Check for cracks or excess vibrations	✓	
Inspect shaft	Check for misalignment and excess vibrations		✓
Inspect noisy operation and excess vibration of pump	Damaged impellers can result in excess vibration and noise		✓
Check inlet and exit temperature of fluid being pumped	Must be in range specified in the operator's manual		✓
Check for corrosion and worn out parts on the pump	Fluid leakage and contamination can cause corrosion of parts.		✓
Check pump to motor coupling	Check for loose nuts, bolts and lubrication		✓
Visually inspect all power and control cables	Must be well insulated and away from fluids.		✓
Check drain lines if they are working properly	Check for blockage		✓
Inspect shaft and impeller clearance	Must be within specified ranges		✓
Inspect wear ring clearances	Adjust to specified clearances when they have doubled		✓
Inspect seal water and drain piping	Flush seal water and drain piping		✓

7.5 Belts

Belts are used for transport of coal, ash and other material at the station. Rubber and balata belts are the main types of belts used because of the conditions of service. Belts transport coal from the offloading bay to coal bunkers and from the bunkers to the power plant and distribute it to boilers. Ash belts transport ash and mud from the ash hopers to the ash plant. Failure of the belt system is catastrophic as it can lead to downtimes and pollution of the environment.

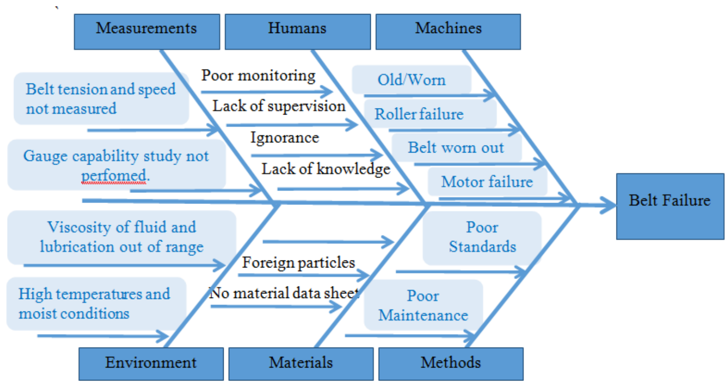


Figure 13 Fishbone diagram for conveyor belts

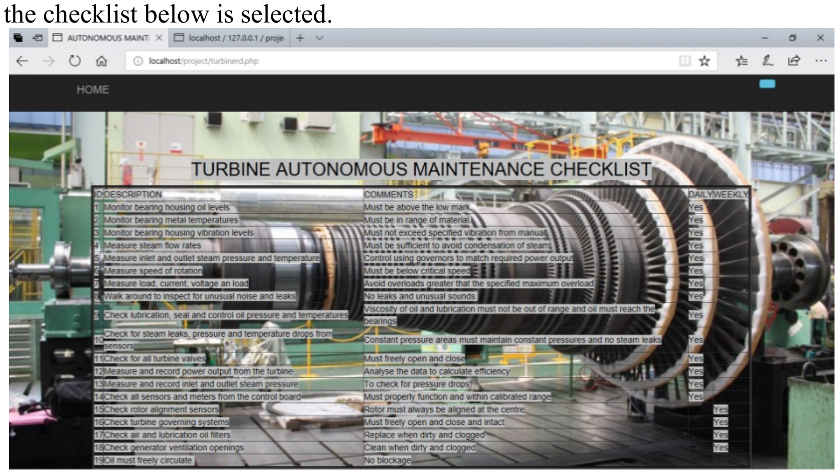
Belt operators can continuously monitor the belt condition using the checklist below. The checklist is developed based on the fishbone diagram and other causes of belt failure hence the steps are developed to mitigate these failure causes and prolong belt life.

DESCRIPTION	COMMENTS	MAINTENANCE FREQUENCY	
		DAILY	WEEKLY
Check belt tracking and tension.	Check for misalignment and sagging.	✓	
Check walkways	Make sure walkways are clear	✓	
Check belt lacing, surface and edge	Check for belt wear, grooves and cracks	✓	
Check drivetrain and sprockets	Check for proper lubrication, tension and wear	✓	
Inspect driving motor	Check temperature, mounting bolts and abnormal noise		✓
Inspect reducer	Check for oil levels, temperature and proper lubrication.		✓
Check v-belts and O-rings	Check proper sheave alignment. Tension and wear.		✓
Inspect the whole conveyor assembly	Check all bolts for tightness and listen for any abnormal noise and check any catch points		✓
Inspect belt support system	Check supports for wear and embedded foreign objects		✓

Inspect conveyor gear box	Check for abnormal vibration and proper tracking of drivetrain		✓
Inspect belt chain	Ensure proper lubrication		✓
Inspect belt safety devices	Check guards for belt, emergency stop functionality		✓
Inspect idlers	Check for wear on return and troughing idlers.		✓
Check all control equipment	Must properly function and be in the calibrated range		✓
Check bearings, pulleys and rollers	Check for wear, lubrication and abnormal sounds		✓

7.6 Database and software design

The main purpose of the database is storage of AM checklists for the critical equipment for easy access by operators, and storage and retrieval of plant KPI records for analysis by engineers and maintenance personnel. The software serves the purpose of providing a user interface so that the data can be accessed for use and also entered into the database. Through the Systems, Applications and Products in Data Analysis and Processing (SAP) interface, the software can be used to analyze the KPI's through graphs and charts giving a forecast of the organization's maintenance from its current performance. Upon logging into the system, the homepage is displayed where the user is prompted to select the desired activity which is accessing the AM checklists, accessing the AM procedures or going to the KPI's data. The options are accessed through a zoom in process. Upon selecting the AM checklists option, the user is given an option to choose the specific critical equipment checklist required. When a specific critical equipment is selected, the AM checklist is displayed which the operators can refer to. For example when turbine is selected, the checklist below is selected.



ID	DESCRIPTION	COMMENTS	DAILY	WEEKLY
1	Monitor bearing housing oil levels	Must be above the low mark	Yes	
2	Monitor bearing metal temperatures	Must be in range of material	Yes	
3	Monitor bearing housing vibration levels	Must not exceed specified vibration from manual	Yes	
4	Measure steam flow rates	Must be sufficient to avoid condensation of steam	Yes	
5	Measure inlet and outlet steam pressure and temperature	Control using governors to match required power output	Yes	
6	Measure speed of rotation	Must be below critical speed	Yes	
7	Measure load, current, voltage an load	Avoid overloads greater that the specified maximum overload	Yes	
8	Walk around to inspect for unusual noise and leaks	No leaks and unusual sounds.	Yes	
9	Check lubrication, seal and control oil pressure and temperatures	Viscosity of oil and lubrication must not be out of range and oil must reach the bearings	Yes	
10	Check for steam leaks, pressure and temperature drops from sensors	Constant pressure areas must maintain constant pressures and no steam leaks	Yes	
11	Check for all turbine valves	Must freely open and close	Yes	
12	Measure and record power output from the turbine	Analyse the data to calculate efficiency	Yes	
13	Measure and record inlet and outlet steam pressure	To check for pressure drops	Yes	
14	Check all sensors and meters from the control board	Must properly function and within calibrated range	Yes	
15	Check rotor alignment sensors	Rotor must always be aligned at the centre		Yes
16	Check turbine governing systems	Must freely open and close and intact		Yes
17	Check air and lubrication oil filters	Replace when dirty and clogged		Yes
18	Check generator ventilation openings	Clean when dirty and clogged		Yes
19	Oil must freely circulate	No blockage		

Figure 14 Turbine AM checklists displayed.

On the homepage, when the KPI option is selected, it displays a page where a specific KPI is selected and when the KPI has been selected, the page with options of inputting the measured KPI values or viewing the records is displayed. The records are presented as tables, graphs and chart. The data displayed in records is used for maintenance analysis in plotting graphs and charts.

7.7 AM implementation flow chart

The step by step AM implementation procedure for the plant is summarized in the flow chart below. First the major aspects of AM are outlined on the fishbone diagram with the effect being overall equipment effectiveness. Several AM factors which lead to improved OEE are given as the cause in the diagram. A summary of the implementation steps in their order is outlined in the flow chat with specific points given as a guide to implementing the steps.

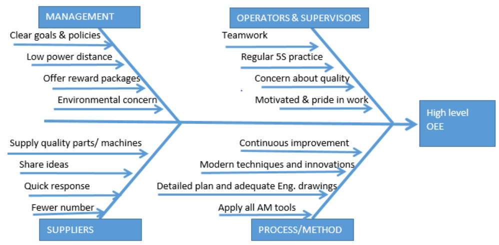


Figure 16 Ishikawa diagram for improving OEE

8. Recommendations

The thermal plant must improve its data capturing methods and keeping of maintenance records. Equipment history is very important in analyzing failures and developing maintenance strategies therefore to avoid corrective maintenance, equipment data must be captured and recorded in and organized form. The records are also important when analyzing equipment for maintenance and evaluating its life cycle costs therefore it is necessary to keep the records.

The organization has a number of KPI's which it uses to monitor performance. It is necessary to increase the number of KPI's and also include important ones like manpower utilization, ration of emergency work to planned works, schedule compliance, ratio of maintenance costs to total costs and balanced score card. These performance indicators give a brighter picture on the success of the maintenance programs of the organization.

The database can be improved so that operators can compare the maintenance work they have performed to the programmed checklists. The Database must also be linked to SAP so as to monitor the equipment in real time and be able to generate notifications if AM has not been performed. The KPI monitoring software can also be advanced to be real time and plot graphs and chats instantaneously so as to indicate the success of AM as it is implemented. When linked to SAP, the software must be able to record the KPI parameters directly from equipment, post the information to the database for storage and retrieve it to plot real time graphs without any human intervention.

9. Conclusion

The research study developed the Autonomous Maintenance implementation strategy for the thermal power generation plant. The database and software were developed using phpmyadmin and MySQL queries so that they can be interfaced with SAP to eliminate the need for training operators on new software which can cause resistance.The study was based on an investigation of the organization's maintenance strategies through analysis of previous maintenance and equipment data, discussions and interviewing management and maintenance personnel and observing the equipment functioning.The AM procedures were made accessible through the database and equipment performance monitoring was simplified through the KPI monitoring software which makes it easy to track the advantages brought by AM implementation.

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Biography

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