Adjudging the Efficacy of Total Productive Maintenance: Case Study

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Abstract
This research study was undertaken to implement and adjudge the efficacy of Total Productive Maintenance at case study organization which is public utility oil firm. The study utilized both quantitative and qualitative methodologies, periodic plant visits and a Maintenance Department Analysis (MDA) tool for benchmarking and reviewing the company's maintenance status at one of their major depot facility major. The average score from the MDA obtained was 2.3 and showed potential areas to be improved when formulating the TPM strategy for the company. Other methods such as the ABC analysis for critical equipment identification were also used in this study, and key performance indicators data for calculating Availability Performance (AP) and Overall Equipment Effectiveness (OEE) were identified as well. The OEE was found to be 77% and a people focused model for TPM formulated with the purpose of increasing the OEE value to the target world class level of 85% as well as achieving the desired state.

1. Introduction
Effective maintenance and asset management are a high leverage contributor to business profitability, through it impact on critical areas such as; safety, product quality, equipment capacity, health and the environment, and also the cost of production (Bentley, 2016). Maintenance is defined as all actions appropriate for retaining equipment in, or restoring it to, a given condition (Dhillon, 2002). The company has for been using two main maintenance strategies - breakdown maintenance and preventive maintenance, which however have not been effective enough as equipment failures are rapid and instantaneous leading to a much lower productivity than expected. TPM is not only a modern maintenance practice but also a system (culture) that takes advantage of the abilities and skills of individuals in an organization in order to attain maintenance effectiveness thus keeping costs as low as possible while improving equipment and machine efficiency. Currently, most of the plant equipment failures are attended by external vendors which are proving to be very costly. TPM is a modern maintenance technique which suits well an environment with automation and technological advancements, and since its pillar approach includes employee training, this calls for multi-skilled and revitalized employees who will not only be involved in plant maintenance but also have knowledge as to why they are doing so. If TPM is well implemented, equipment operates without breakdowns, everyone's work is easier, and the company is more profitable, and working conditions are improved.

2. Justification
In today's world of vast technological advancements, a great number of companies regardless of how much productivity and profits made in previous years, there is still need to be better and to reach maximum potential, as their survival depends on how they rapidly innovate and improve. Total Productive Maintenance (TPM) is part of the benchmarking efforts seen or identified as the best in class manufacturing improvement process and is defined

as; A systematic approach to understanding the equipment's function, its relationship to the product quality as well as the probable cause and frequency of failure of the equipment critical components (Nakajima, 1984). TPM involves every member in an organization i.e. the management, operators and the maintenance department for it to be successful and should be recognized that the benefits are for both the company and workers. In general, TPM can be considered as the medical science of machines (Venkatesh, 2007) as it focuses holistically on machinery health. The main purpose of this research is to implement a modern maintenance plan and analyze its effectiveness over the existing maintenance strategies, which will address issues of equipment failure by utilizing existing resources at the same time increasing efficiency and production and thus enabling the company to meet its main objectives and core values. TPM program is therefore aimed at providing a permanent and long term solution as a high rate of return compared to resources invested may be expected if implemented correctly.

3. Literature review

The purpose of maintenance is mainly to minimize maintenance cost and down-time cost at a given quality of production, while at the same time fulfill the requirements of safety i.e. conforming to ISO standards (Mugwindiri, 2016). A maintenance strategy is defined simple as the management method used in order to achieve the maintenance objectives, and these objectives being the targets assigned to or accepted by the management and maintenance department which include; availability, cost reduction, environment preservation, safety and product quality (Gustav Fredriksson, Hanna Larsson, 2012). After the two main forms of maintenance which are breakdown maintenance and preventive maintenance, predictive maintenance has been developed to address the shortcomings of the later.

3.1 Total Productive Maintenance (TPM) review

TPM is a well proven tool as it as it seeks to maximize overall equipment effectiveness, establish a thorough maintenance system for the entire life span of the equipment, bring department together in an organization, and involve every employee, from top management to hourly employees. Companies practicing TPM invariably achieve startling results, particularly in reducing equipment break downs, minimizing idling and minor stoppages, and lessening quality defects and claims boost in productivity, trimming labor costs, shrinking inventory, cutting accidents and promoting employees morale as shown by the increase in improvement suggestions. Basically there are two major steps towards a successful TPM implementation and these will be explained in detail below. The starting point is identifying the key area in a company is planning, then the actual stage of TPM implementation. Continuous improvement to the program is done relentlessly and maintained and the use of task groups applied to cement the implementation process. A distinctive TPM process should begin with three key areas: these are policy and strategy, management and improvement of the organization and also how the TPM program will be implemented through use of task groups. The following points are key to formulating a TPM strategy: commitment, customer satisfaction, quality losses, participation by all, process measures and continuous improvement as well as personal accountability and development.

Commitment – As it is one of the main themes of TPM, commitment from the management down through to all members of the organization (shop floor) is key. Each employee needs to be committed to and accountable for continuous quality improvement of their work.
Customer Satisfaction – This is part of marketing and business planning, the understanding and satisfying of customer needs and expectations should be a key objective, remembering that many members of an organization do not have direct contact with the external customer. It is important to remember that a dissatisfied customer rarely returns. At a local level, it should also be borne in mind that each person has a customer and a supplier even on the factory floor.
Quality Losses –these include waste of resources, damage to property, loss of customer satisfaction and opportunity to add value to the product and so on. They are caused by failure to utilize human and resources to their maximum potential effectively. TPM improves change of culture and mindset and helps eliminate the 'us and them' attitude which eventually leads to continuous attention towards closing the corporate gap in an organization.
Participation by all –team work applied which high spirits and morale tends to yield positive results. A strategy formulated with a bias towards total strengths and abilities of employees i.e. through small group activities working together is recommended as TPM is all about full employee involvement.
Process Measures and Continuous Improvement – the kaizen approach on areas such as performance of people and processes need to be monitored and should be built upon current process measures and standards that are acceptable.

The process measures need to be applied everywhere across the functional areas of the organization and continuous assessment of potential and persistent problems applied.
Personal Accountability and Development – it is important for a strategy to promote continuous training, appraisal and development of the individuals at every level as this does not only benefit the employees personally but the organization as a whole.

3.6.1 Management structure

This stage involves establishing an effective organizational structure, basically to establish, audit and keep under review an effective management system (maintenance management). Maintenance management is a support organization, in a world-class organization the mission of maintenance is to achieve and sustain optimum availability of the business productive assets (plant, equipment, vehicles etc.). Following is a systematic TPM organizational structure.

3.2 Improving organization

This stage is more of a continuous improvement process because improving the organization means looking at the working environment, the measurement of performance, improvement objectives and plans, and monitoring and reviewing processes. The physical environment and relationship between the individual and the organization and other employees should be structured so that each individual and team is aware of its contribution. Improvement goals need to be closely integrated with the corporate objectives and should be considered separate to new capital intensive project. Plans for improvement of product service, process quality, safety, environmental impact dependability and customer satisfaction are needed at all levels of any process. Figure 1 shows a schematic TPM improvement process, which is a continuous cycle.

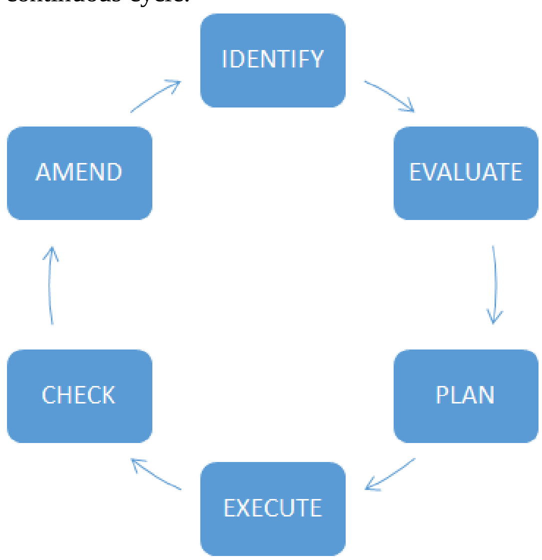

Figure 1.TPM schematic improvement process

It is important to ensure that all plans, targets and performance measurement throughout the organization complement each other and reflect the overall objectives of the mission statement, and help to review the results of improvement plans to obtain a measure of their effectiveness. Equally important is to have an effective reporting and feedback mechanism and structure.

3.3 TPM implementation

The actual stages of TPM implementation are done in twelve (12) steps and these are divided into 4 stages or Nakajima's 5 development activities as some sources present it. This is a theoretical approach although its practical approach is discussed and suggested as well. Following are the stages of TPM implementation:
Stage 1 – This is called the preparatory stage, it involves the first 5 steps of the implementation process which will be described briefly.
Stage 2 – The introduction stage, it can also be named step 6 as it is the only procedure done at this stage.

Stage 3 – The implementation stage, this is done using the 8 pillars of TPM and they have already been discussed earlier and these are steps 7 up to 11
Stage 4 – The institutionalizing stage, this final stage (step 12) involves applying for the PM award as TPM would have reached maturity stage.

Depending on the industry, not all pillars can be implemented, as some companies have specific target areas. Figure 1 table describes Nakajima's 12 steps in detail.

Table 1.Nakajima's 12 implementation steps

STEPS	DESCRIPTION
1.	Announcement to everyone (employees) by Top Management about the TPM introduction in the organization. o State tpm objectives in the company newsletter o Place articles on tpm in the company newsletter
2.	Launch educational campaign and propaganda for TPM o For managers – offer seminars according to level o For general workers – offer slide presentations
3.	Setup organizations to promote and support TPM o Form special committees at every level o Establish central headquarters and assign stuff
4.	Establish TPM working system and basic TPM policies and goals o Set goals o Analyze existing condition
5.	Formulate a TPM master plan o Prepare detailed implementation plans
6.	Hold a TPM kick off o Invite all; suppliers, external customers, related companies and affiliated companies etc.
7.	Improve effectiveness of each piece of equipment (KK, QM) o Form project teams o Select equipment model
8.	Develop an autonomous maintenance program (Jishu Hozen Pillar) o Promote the 7 steps. o Build diagnostic skills and establish worker procedures for certification.
9.	Develop a scheduled maintenance program for the maintenance department (PM) o Include periodic and preventive maintenance o Include management of spare parts, blue prints, job cards etc.
10.	Conduct training to improve maintenance and operation skills (OT, ET) o Train leaders together o Have leaders share information with group members
11.	Develop initial equipment management program (EEM) o Use maintenance prevention design o Use LIFE CYCLE COST ANALYSIS
12.	Perfect TPM implementation and raise TPM levels o Apply for the PM award o Set higher goals

3.4 Critical equipment selection

Resources are very limited everywhere and it is therefore necessary to determine how to distribute them. The reason being to concentrate resources on most significant processes that have more negative potential impact consequences. Thus a more robust production will be obtained by continuously improving the most critical equipment (Gustav Fredriksson, Hanna Larsson, 2012). There is no formal definition for critical equipment, but in relation to this context, critical equipment is that equipment whose failure has the highest potential impact (negatively) on the business goals and objectives of the company. There are also various methods for the selection of critical equipment and they all look at various factors. The best method to use for classification of equipment is the Always Better Control (ABC) classification of equipment by Ylipää (2012) used in order to assess the need of maintenance and to optimize the maintenance activities. The classification is made with regard to six factors (SQTOFM):
S - Safety risk associated with breakdowns (**Safety**)
Q - Quality problems, customer complaints or scrap (**Quality**)
T - The extent of time during which the equipment is used for production (**Available Time**)
O - Obstacles due to equipment breakdown in production, which affect the lead time
F - Failure frequency **(Failure**)
M - Mean Time To Repair (**Maintainability**)

The rules for classification of equipment used in the ABC method are shown by Table 2 below together with the classification flowchart [Fig 6] with each step described in detail.

Table 2 - ABC rules for critical equipment classification

S	High Risk	Low Risk	Insignificant Risk
Q	High Risk	Low Risk	Insignificant Risk
T	24 hours/day	8-24 hours/day	8 hours/day
O	Cause a stop in the whole production process	Do not stop the process but causes losses	Do not stop production processes
F	More than; 1 failure/month	Between; 1 failure/2 months and 1 failure/6 months	Less than; 1 failure/6 months
M	MTTR > 2 hours	0.5 hrs. < MTTR < 2 hrs.	MTTR < 0.5 hours

3.5 Availability performance

The ability of equipment to function properly despite failures and disturbances and maintenance resource limitations is defined as Availability Performance. This factor will be critical in analyzing the case study company. It is basically a measure of availability and it is broken down into three concepts: Functional Reliability (MTBF), Maintainability (MTTR) and Supporting (MWT).

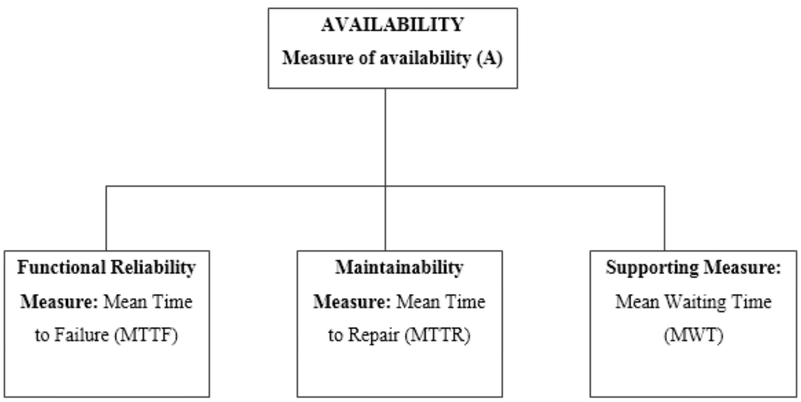

Figure 2.Relationship between the concepts of availability

Functional Reliability is the probability that a piece of equipment will function without interruption at a given time under specified conditions and Availability is defined as the probability that the system is in an operational state at the time of interest (Saled Al. Rawahi, Sudhir C. V., 2015). Figure 3 shows the relationship between the reliability, maintainability and the availability.

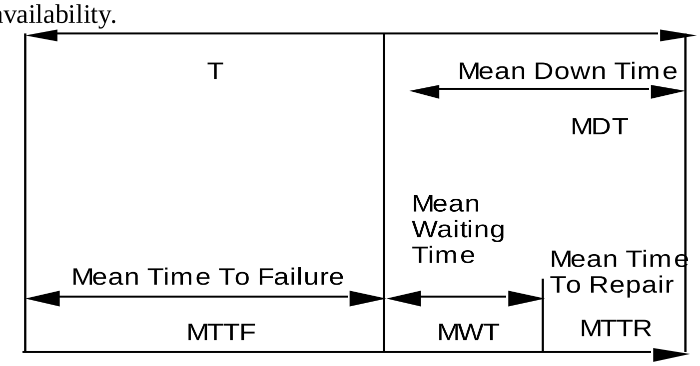

Figure 3.Relationship between the Reliability, Maintainability and Availability

Machine Reliability is the probability that a system will perform as expected for a given time period of time when used under specified operating conditions. The prediction is dependent on MTBF and instantaneous failure frequency (λ) which is simply the inverse of MTBF expressed in failures per hour.

3.6 Overall equipment effectiveness

OEE is a way to monitor and improve the efficiency of manufacturing processes and has become an accepted management tool to measure and evaluate plant floor productivity. OEE is broken down into three measuring metrics of Availability, Performance, and Quality. These metrics help gauge your plant's efficiency and effectiveness and categorize these key productivity losses that occur within the manufacturing process. OEE empowers manufacturing companies to improve their processes and in turn ensure quality, consistency, and productivity measured at the bottom line. There are many events within a manufacturing process that can affect OEE and the major goal is to minimize or reduce the causes of inefficiency in the manufacturing environment. The 6 major losses are identified as the events hindering manufacturing processes and these are: machine breakdowns, machine adjustments/setups, machine stops, machine reduced speeds, machine startup bad parts, and machine production bad parts.

3.7 Improving equipment failures

The major reason behind Engineering Maintenance is equipment failure. It can be defined as the abnormality from a required function of a machine or termination of the ability of a machine to perform a required function(Dhillon, 2002) and these failures can be categorized as potential failures and functional failures. There are several techniques and tools that can be used within improvement programs to systematically solve failure problems. Below is the, Failure Mode and Effect Analysis, Fault Tree Analysis and the Fishbone diagram among a few selected with relation to this context.

4. Case study

The case study firm is government utility organization which was established in 1983 to procure, store and distribute fuel and related petroleum products for the local market. In 2011 the company was restructured to cab the effects of inefficiency that existed due to being a monopoly. Company's focus is on a value chain that delivers product to customer expectations all the time. All its operations are guided by the quest to adhere to stringent safety, legal, statutory, environmental, health and safety standards. It has committed to provide superior service through focus on customer needs, teamwork, quality-guided processes and passion for excellence. The firm offers pipeline transportation, storage, handling and distribution services of petroleum products which are diesel, petrol, unleaded petrol, illuminating paraffin and Jet A1 as well as ethanol. It is also responsible for collecting government levies such as duty, road levy, pipeline fees for both local and foreign pipeline and remitting it to the respective authorities and companies. On receipt, these petroleum products are tested for quality in a laboratory. The entity also stores bonded products, duty paid products and administer product clearance with Revenue Authority on behalf of clients.
The company's major mandate entail owning all upstream assets namely depots and pipeline. It also has to maintain, upgrade, replace and invest in both existing and new infrastructure. As well as promoting the usage of pipeline and storage facilities by third parties. Client satisfaction is always key to the company hence the proper adhering to the key responsibilities is an important aspect and the company has been doing that excellently. The main underground storage facility is located 40m below the ground level, an access tunnel leads to the main entrance which consists of two trap doors for pressure balance as the facility works with pressure lower than that of the atmosphere. The underground facility is then divided into 2 sections, the service area in which all condition monitoring is carried out and the pipe tunnel where the caverns are located.

The maintenance approach is approximately 80% reactive and 20% proactive as most of the equipment breakdowns is attended by procurement companies. The maintenance department attends mostly to autonomous maintenance activities such as inspections, lubrications and so on, whilst the operations department deal with plant related processes such as fuel storage and transit within and outside the depots via the pipeline. The laboratory department monitors quality assurance standards by testing all product as it enters or leaves the depot. The loading bay department most of their work is in loading trucks and clearing fuel to service stations which is basically the final stage of the shop floor activities.

5. Maintenance system findings

The purpose of the Maintenance Department Analysis (MDA) is to evaluate the maintenance effectiveness of the company and compare it with other companies of the similar industry globally, and in this case; MDA of case study firm was carried out on the 1st of May 2017. The average MDA score was calculated and the results summarized as follows:

$$\mathrm{MDA_{ave}} = \frac{\sum_{x=1}^{45} S(x) + n}{x - n}$$

$$= \frac{63+12}{33}$$

$$= \underline{\mathbf{2.3}}$$

Where, S(x) is the score for question x (for $1 \leq x \leq 45$) and n is the number of questions not applicable (their score being -1 for each). The maximum value for average MDA is 4 and the lowest is 1 hence with an average MDA score of 2.3 for the case study firm attained a fair score which means there is room for improvement i.e. through application of modern maintenance concepts such as TPM.The maintenance department responsibilities and work are clear, well communicated and have good coverage but are not fully documented. The usability and clarity of the maintenance organization's document management system is good. The organizational support to continuous improvements efforts is moderate. Training is provided to new planners by supervisors for at least the first month. Education concerning new technology and changes in equipment is provided not to all employees, but to some in less than one year. Maintenance competence and work quality of performed maintenance tasks are considered to be good. When the maintenance job is completed the craftsmen that performed the job report the actual working time, used material, downtime, and other data. Less than 40% of the preventive maintenance (PM) program cover critical equipment. From 40% to 59% of the PM program is annually checked against corresponding item's history to ensure good coverage of the program. The frequency of the preventive maintenance program is based on the Run time only. None of the total amount of work orders has been generated from preventive maintenance inspections as they do not exist. The availability of critical spare parts is in storage at a range of 70% to 79%. . Maintenance controls the inventory of spare parts and again 70% to 79% of the maximum and minimum levels of stored materials is specified. Less than 40% of all maintenance operations utilizes Computerized maintenance management system (CMMS) at present. CMMS data structured and updated at approximately less than 40% as well. No operations personnel generate work order requests as they do not exist and operators are trained to perform inspections.

Risk analysis used from 60% to 74% of the assets. No RCM methodology is used on critical equipment to adjust or refine the PdM program and 40% to 59% of all failures are clearly identified to its root cause. No failures can accurately be tracked by work order history. Failure analysis is conducted by the use of an analysis tool such as fishbone, tree, five why's or Pareto, to assure accuracy and standardization for each analysis. No failure frequencies is calculated according to "The Six Failure Patterns" included in the RCM methodology. The concept 'Life cycle cost' or similar is regarded when initial investments are planned but not utilized or taken into account when its condition is determined. The organization's financial knowledge regarding condition determination and classification of assets is limited. The case study firm has well maintained depots with state of art equipment but however the MDA score of 2.3 shows that there is room for improvement in weak areas such as Reliability engineering, Maintenance Work orders, Operator maintenance, CMMS and financial planning and this can be done chiefly through application of modernized engineering maintenance strategies such as TPM.

6. Data analysis

Table 3 gives company equipment from the main terminal depot. The sheet contains both above ground (A/G) and underground (U/G) equipment showing their status, operating hours as well as history and number of failures where necessary.

Table 3.Case study firm equipment

MACHINERY/ EQUIPMENT		CURRENT STATUS	HISTORY/NUMBER OF FAILURES PER MONTH	REQUIRED OPERATING HOURS/DAY
1.	A/G Fire Engine 1	OK	NO PROBLEM	8
2.	A/G Fire Engine 2	DOWN	TENDER STAGE	8
3.	A/G Hydraulic Power Pack	OK	NO PROBLEM	24
4.	U/G Hydraulic Power Pack	OK	NO PROBLEM	8-24
5.	A/G Jockey Pump	OK	NO PROBLEM	24
6.	U/G Fire Engine	OK	NO PROBLEM	8
7.	U/G Electric Fire Water Pump	OK	NO PROBLEM	8
8.	MCC Room Cooling Fan	OK	NO PROBLEM	24
9.	U/G Jockey Pump	OK	NO PROBLEM	24
10.	S/BY Generator 1	OK	NO PROBLEM	8
11.	S/BY Generator 2	DOWN	TENDER STAGE 1 F/M	8
12.	S/BY Generator 3	OK (OFF)	NO PROBLEM	8
13.	S/A Inlet Fan 1	OK	NO PROBLEM	24
14.	S/A Inlet Fan 2	OK	NO PROBLEM	24
15.	S/A Extraction Fan 1	OK	NO PROBLEM	24
16.	S/A Extraction Fan 2	OK	NO PROBLEM	24
17.	P/T Inlet Fan 1	OK	NO PROBLEM	24
18.	P/T Inlet Fan 2	NO FAN	TENDER STAGE	24
19.	P/T Extraction Fan 1	OK (OFF)	NO PROBLEM	8-24
20.	P/T Extraction Fan 2	NO FAN	TENDER STAGE	8-24
21.	S/A Refrigeration System	DOWN (FOR RENOVATION)	TENDER STAGE	8-24
22.	P/T Refrigeration System	DOWN (FOR RENOVATION)	TENDER STAGE	8-24
23.	Transformer	OK	NO PROBLEM	24
24.	Transformer Fan	DOWN	RADIATOR LEAKS	24
25.	Ground Water Pump 1	OK	NO PROBLEM	8-24
26.	Ground Water Pump 2	OK	NO PROBLEM	8-24
27.	Generator Cooling Pump 1	OK	NO PROBLEM	8-24
28.	Generator Cooling Pump 2	OK	NO PROBLEM	8-24
29.	HVAC Cooling Water Pump 1	OK (OFF)	SYSTEM UNDER REPAIR	8-24
30.	HVAC Cooling Water Pump 2	OK (OFF)	SYSTEM UNDER REPAIR	8-24
31.	Sewage Pump 1	OK	NO PROBLEM	8
32.	Sewage Pump 2	OK	NO PROBLEM	8
33.	Grinder	OK	NO PROBLEM	8
34.	Drain Pit Pump – RC51	OK	NO PROBLEM	24
35.	Drain Pit Pump – RC61	OK	NO PROBLEM	24
36.	Drain Pit Pump – RC21	OK	NO PROBLEM	24
37.	Drain Pit Pump – RC14	OK	NO PROBLEM	24
38.	DC 03 Product Pump	DOWN	TENDER STAGE	8-24
39.	DC 03 Seepage Pump	OK	NO PROBLEM	24
40.	DC 04 Product Pump	OK	NO PROBLEM	8-24
41.	DC 04 Seepage Pump	OK	NO PROBLEM	24
42.	PC 05 Product Pump	OK	NO PROBLEM	8-24
43.	PC 05 Seepage Pump	OK	NO PROBLEM	24
44.	PC 06 Product Pump	OK	NO PROBLEM	8-24
45.	PC 06 Seepage Pump	OK	NO PROBLEM	24
46.	JC 01 Product Pump	DOWN (REMOVED)	REMOVED AND PLACED IN DC03	8-24
47.	JC 01 Seepage Pump	OK (OFF)	NO PROBLEM	24
48.	JC 02 Product Pump	OK (OFF)	NO PROBLEM	8-24
49.	JC 02 Seepage Pump	OK (OFF)	NO PROBLEM	24
50.	P/T Actuators	OK	NO PROBLEM	24

Equipment Criticality selection was done using the ABC method .The following symbols and their meanings are defined here:

 - High risk

 - Low risk

- Insignificant risk

After completing the equipment selection using ABC method, the resulting Table 4 shows critical equipment which is classified as A and B, and these require preventive maintenance since their failure has the most significant potential consequences on the company business. Equipment classified as C however has less significant impact and can be allowed to breakdown and then maintained, i.e. breakdown maintenance and corrective maintenance strategies.

Table 4 - Critical Equipment

A ( )	**B ( )**	**C ( )**
• U/G Hydraulic Power Pack	1. Ground Water Pump	1. A/G Hydraulic Power Pack
• U/G Fire Engine (2)	2. HVAC Cooling Water Pump	2. P/T Inlet Fan (2)
• MCC Room Cooling Fan	3. A/G Fire Engine (2)	3. P/T Extraction Fan (2)
• S/BY Generator 1		4. S/A Refrigeration System
• S/A Inlet Fan (2)		5. P/T Refrigeration System
• S/A Extraction Fan (2)		6. Transformer Fan
• Transformer		7. HVAC Cooling Water Pump
• Drain Pit Pumps (4) RC-(14,21,51,61)		8. Sewage Pump
• Product Pumps (6) (DC,PC&JC)		9. Grinder
• Seepage Pumps (6) (DC,PC&JC)		10. S/BY Generator 2
• P/T Actuators (all)		11. S/BY Generator 3

Critical equipment selected above is analyzed for its reliability and availability so as to come up with an accurate and detailed TPM design program for the company. The detail of the equipment to be used for calculations was pulled from mostly job cards, manuals, interviews and technicians experience. Where there was unavailability of some equipment data, assumptions will be made and clearly stated. The service life of 3 years (31/03/2014 – 31/03/2017) is used i.e. 156 week while a shift goes from Monday to Sunday in the operations department i.e. 7 days a week. The following equations will be used in calculating required information.

Equation 1 - Mean Time before Failure (MTBF):

$$\text{MTBF} = \frac{\text{Available Time} - \text{Down Time}}{\text{Number of failures}}$$

Equation 2 - Mean Time to Repair (MTTR):

$$\text{MTTR} = \frac{\text{Total Repair Time}}{\text{Number of failures}}$$

Equation 3 - Mean Waiting Time (MWT):

$$\text{MWT} = \frac{\text{Total Waiting Time}}{\text{Number of failures}}$$

Equation 4 – Availability:

$$\text{A} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR} + \text{MWT}} \text{ x } 100\%$$

Equation 5 - Failure Rate:

$$\lambda = \frac{1}{\mathrm{MTBF}}$$

Equation 6 – Reliability (t):

$$\mathrm{R(t)} = e^{-t\lambda}$$

where, t is the time since last failure.

For all the equipment, the same method (availability performance) is used and values are calculated using Microsoft excel spreadsheet. All the values calculated are tabulated in Table 5.

Table 5.Availability Performance and Reliability for Critical Equipment

CRITICAL EQUIPMENT	**MTBF (hours)**	**MTTR (hours)**	**MWT (hours)**	**MACHINE AVAILABILITY (A)**	**MACHINE RELIABILITY R (T)**
U/G Hydraulic Power Pack	4364	2	2	**99.91%**	**23.76%**
A/G Fire Engine	8616	96	24	**98.63%**	**43.52%**
U/G Fire Engine	4348	8	12	**99.54%**	**67.95%**
P/T Product Pumps	8588	36	112	**98.31%**	**79.08%**
P/T Seepage Pumps	6450	6	96	**98.44%**	**23.26%**
P/T Actuators	2619	1	1	**99.93%**	**31.52%**
MCC Room Cooling Fan	13056	36	12	**99.63%**	**77.31%**
S/BY Generator 1 (main)	1080	3	9	**98.90%**	**39.84%**
S/A Inlet Fan(s)	8716	4	16	**99.77%**	**46.26%**
S/A Extraction Fan(s)	6537	6	9	**99.77%**	**25.33%**
Drain Pit Pump(s)	8703	3	30	**99.62%**	**36.85%**
Transformer	26166	18	24	**99.84%**	**41.70%**
Ground Water Pump(s)	8719	10	7	**99.81%**	**27.68%**
HVAC Cooling Water Pump	5788	12	24	**99.38%**	**55.77%**

Using the Availability Performance and Machine Reliability analysis the Overall Equipment Effectiveness (OEE) is then calculated. OEE is used for monitoring and improving the efficiency of manufacturing processes. It is broken down into three measuring metrics of Availability, Performance, and Quality and these metrics help gauge the plant's efficiency and effectiveness and categorize the key productivity losses that occur within the manufacturing process.The following metric equations will be used in calculating OEE**:**

Calculating availability

$$\text{Availability} = \frac{\text{Run Time}}{\text{Total Time}}$$

Calculating performance

$$\text{Performance} = \frac{\text{Total Count}}{\text{Target Count}}$$

Calculating quality

$$\text{Quality} = \frac{\text{Good Count}}{\text{Total Count}}$$

Calculating OEE

Overall Equipment Effectiveness = Availability x Performance x Quality x 100%

Table 6 gives the 14 week OEE assessment. Calculations were done using a Microsoft Excel spreadsheet.

Table 6.Plant Overall Equipment Effectiveness

DATE (weekly)	**Availability (A)**	**Performance (P)**	**Quality (Q)**	**OEE (A x P x Q)**
24/10/16 – 31/10/16	80.95%	99.90%	99.99%	**80.86%**
07/11/16 - 14/11/16	88.10%	95.83%	94.17%	**79.51%**
21/11/16 - 28/11/16	78.57%	97.22%	99.43%	**75.95%**
05/12/16 - 12/12/16	82.14%	96.00%	99.38%	**78.36%**
09/01/17 - 16/01/17	84.52%	94.44%	99.41%	**79.36%**
23/01/17 - 30/01/17	78.57%	95.45%	99.05%	**74.29%**
06/02/17 - 13/02/17	80.95%	96.97%	99.06%	**77.76%**
20/02/17 - 27/02/17	77.38%	98.42%	99.47%	**75.75%**
06/03/17 - 13/03/17	85.71%	96.67%	96.55%	**80.00%**
20/03/17 - 27/03/17	79.76%	95.00%	99.95%	**75.73%**
03/04/17 - 10/04/17	80.95%	96.43%	99.63%	**77.77%**
17/04/17 - 24/04/17	85.71%	94.00%	98.60%	**79.44%**
01/05/17 - 08/04/17	83.33%	96.15%	98.72%	**79.10%**
15/05/17 - 19/05/17	77.38%	95.00%	98.95%	**72.74%**

Graphical comparison of critical equipment in terms of A, R (t) and OEE for Availability and Reliability were constructed. This is to create a clear analysis since all the equipment rendered critical came from the underground storage facility. The service area is a separate tunnel with offices, workshops, control room etc. whilst the pipe tunnel contains fuel caverns only.

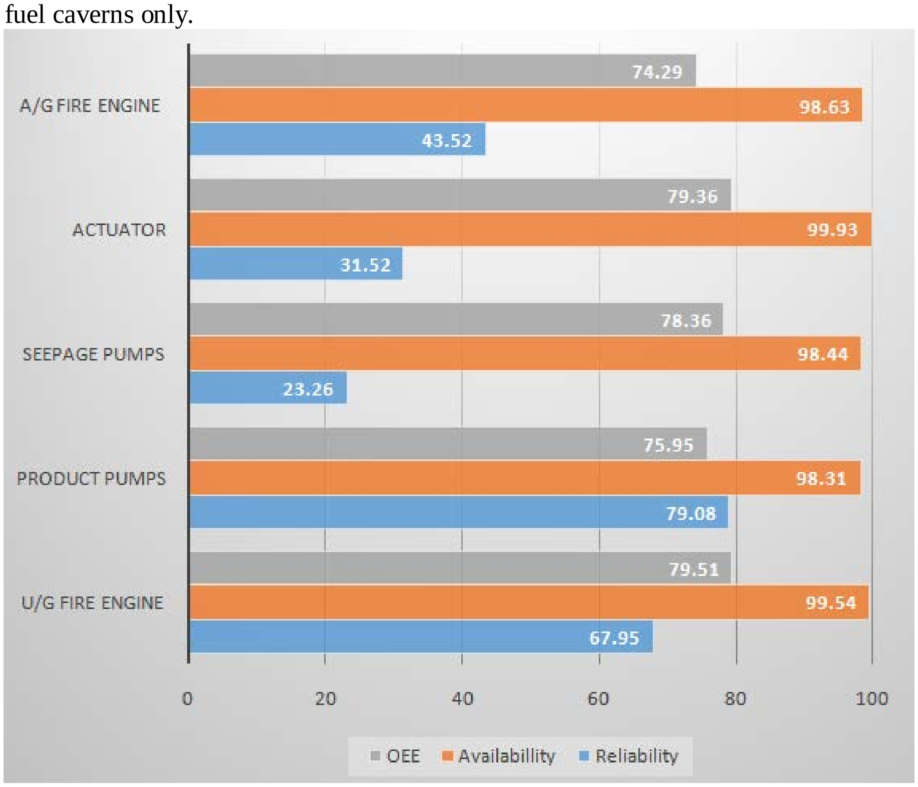

Figure 4.Underground Pipe Tunnel Critical Equipment Analysis

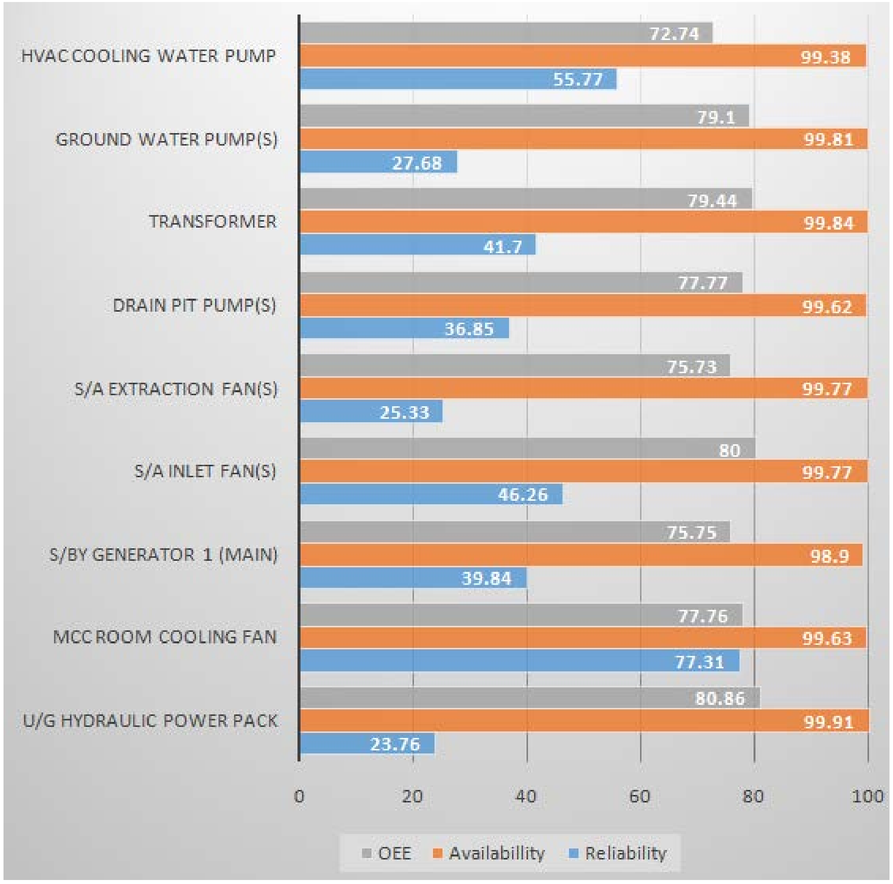

Figure 5.Underground Service Area Critical Equipment Analysis

7. Recommendations

The management staff from all departments should formulate strategy and policy for the maintenance program as this is a team effort. The strategy should not be too complicated with excessive details meaning the details in the implementation plan do not need to be included in the document of the strategy but can be managed separately.
The TPM vision should be biased towards the company vision hence the motives of a successful TPM should be regarded as the vision for the case study organization, which markedly increase effectiveness and productivity while at the same time, increase associate morale and job satisfaction. This will directly impact on the company's vision because a markedly increased production means the company is able to meet the country's fuel requirements as the market share will be largely improved. With an ever growing demand for petroleum products in the country, having motivated workers doing their job adequately puts less strain on the system which in-turn yields happy customers. Thus, a well formulated vision, communicated to the whole organization and understood by the whole organization (simple and straight forward) is of great importance in the continuing work with the strategy. With a well-articulated and applied mission statement, it is inevitable that the company's mandate will be achieved by TPM.

The implementation plan i.e. a description of who will do what in specified time frames, is developed from the road map and this should be covered in the strategy. This approach will also be adopted and used for the implementation process to be described shortly, chiefly because the groups include everyone from management to shop floor and encourages participation by all which is in-line with the vision and mission of the TPM strategy developed. The goal is to obtain cleaner and safer workplaces and that are better organized and more efficient as this will save time, with fewer interruptions, and space by getting away unnecessary tools or by moving the tools not used to often. Sources of problems must be analyzed at an engineering level i.e. FEA, RCA etc. Periodic and preventive maintenance should be Included, as well as management of spare parts, blue prints, job cards etc. The best way is providing the operations and maintenance staff with training that is directed against them. Production or Operations staff needs to further develop their knowledge of Autonomous maintenance and the maintenance staff must be offered the opportunity to develop greater expertise that might be expected of them. Education and knowledge is a basis in order to perform continuous improvement programs. Train leaders together and have them share information with group members. For machine reliability; for the same value of t (time since last failure) which is a fixed value, a decrease in downtime means MTBF is increased, this in turn will reduce the failure rate (λ)as they are inversely related, thus an increase in machine reliability. The critical equipment will now perform for a much longer time without failing. Machine reliability is however very low and it averages 44% for the critical equipment at fuel depot i.e. there is a 44% chance that every critical equipment will function as intended without failing .The average values are presented as follows:

MTBF (hours/week)	156.25
Machine Downtime (hours/year)	35.55
Machine Reliability	44%
Machine Availability	99.39%
Plant Downtime (hours/week)	15.36
Plant OEE	**77.62%**

Hence the case study firm has an acceptable OEE value of range 75-85% but can be upped through adoption of TPM. The study carried out at the depot showed that a decrease of 50% in the average downtime increases the plant OEE values by approximately 10% i.e. to world class level. By implementing TPM, all above areas are targeted and improved hence downtime is largely reduced. The expected results are compared to the existing results obtained through research (case study).

8. Conclusion

The purpose for this research was to formulate a TPM strategy which best suits the petroleum handling case study firm, and then adjudge its efficacy by considering one of its branches (depots) as a working station representing the company as a whole. By lowering the scope on one depot instead of five, the idea was to minimize the timeframe and the workload on the research part. A case study was carried out and the maintenance system analyzed through an MDA questionnaire obtained from other TPM studies on similar industries across the globe. The MDA score was found to be 2.3 on scale of 1-4, which when compared with other companies such it is a fair score (Gustav Fredriksson, Hanna Larsson, 2012). After analyzing the maintenance department at the case study firm, the weak and strong areas which showed that the company has a great potential for improvement were identified especially in the areas such as Reliability engineering, Maintenance Work orders, Operator maintenance, CMMS and Financial Planning. The critical equipment was also identified through the use of the ABC classification model and analyzed for Availability Performance and Overall Equipment Effectiveness of which the results were as follows.

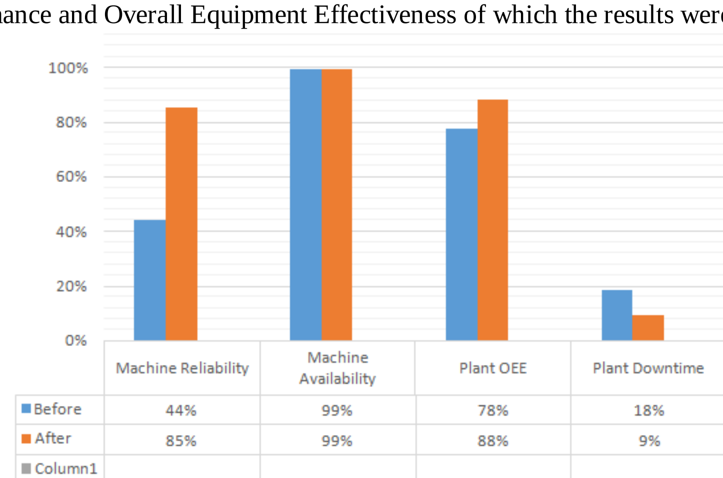

Figure 6.Plant Status (Before and After TPM)

This analysis will help in the detailed formulation of the TPM strategy in future for setting goals and targets aimed at improving the maintenance organization for the company, since this research only introduced a typical framework of how the TPM strategy should be.

The underlying factor in drawing a conclusion towards the achieving of world class level (85% - 90%) is that; the current OEE value of 77% means there is room for improvement through application of modern techniques such as TPM as shown through case studies done by experts such as Mr. Nakajima in the field of maintenance. The proposed strategy and timeframe for project implementation can be improved once the management staff discusses the strategy in detail as this was just a guideline as to how the implementation process can be carried out.

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Biography

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