Overall Equipment Effectiveness (OEE) and Reliability Analysis of the Water Supply Systems in Bonny Island

Pius Mbaebie, Barinyima Nkoi, & Elemchukwu O. Isaac
Department of Mechanical Engineering,
Rivers State University, Port Harcourt, Nigeria.

DOI: 10.56201/ijemt.v8.no3.2022.pg24.36

Abstract
Bonny Island is an island surrounded by water with 24 hours electricity and a home to many multinational companies, but Bonny is yet to boast of more than 2 hours of water supply in a day which is barely enough for individuals and businesses without adequate storage to carry out their daily activities. This research work used Overall Equipment Effectiveness OEE and the reliability analysis to evaluate the operational losses and also to know the factors militating water supply system in Bonny Island for remediation. OEE is formulated of three components, which are availability, performance, and quality. Six big losses such as breakdowns, setup and adjustments, small stops, slow running, start-up losses and production losses; are also important for calculation of OEE. Bonny Water Distribution Plant BWDP has a total capacity of 7.012 Million Litres per Day (MLD) for a population of about 175000 people. In this case study, data was collected for six months in all pumping stations. The result shows that BWDP has an average Availability of 88.84%, Quality of 85.58%, Performance of 83.45% and 61.27% OEE as compared to 90% Availability, 95% Quality, 99% Performance and 85% OEE of Seiichi Nakajima world class OEE system. To minimize these losses and to achieve world class OEE system, it was recommended that there should be reduction in events which are discussed in six big losses section, which include; fault in current, trips, pipeline leakages, water shortages in sump well and others.

Keywords: *Reliability, Availability, Quality, Performance, Overall Equipment Effectiveness, Water Treatment Plant, Mean Time between Failure*

1. INTRODUCTION

Many villages in the Eastern Niger Delta, particularly on Bonny Island, are experiencing severe water shortages. This is due to an increase in groundwater exploitation as a result of increased population density and urbanization in the area. The neighboring rivers, which may have supplemented the groundwater, have been badly polluted by different human activities in the area,

including oil spills and poor sanitation practices (Amadi, 2011; Nwankwoala, 2010)

The community's economic development and standard of living are both impacted by the water supply issues. Economic growth and a higher standard of life are complicated processes that share a similar denominator: the availability of a sufficient and reliable water supply, which is dependent on the supply system's performance and availability. The efficiency, availability, and other operating variables of a water discharge system have a significant socioeconomic impact on the surrounding population. Socio-economic transformation, on the other hand, would be a mirage without an adequate and stable water supply (Adegboyega & Famoriji, 2011).

Water supply activities, on the other hand, tend to be natural monopolies, thus the performance of water supply systems must be evaluated in order to ensure good service levels in the long run. Integrating performance assessment approaches into management practices produces competitive dynamics that promote a culture of efficiency and constant improvement. The key to long-term sustainability is performance assessment, which is described as "any approach that allows for the evaluation of a process or activity's efficiency or effectiveness through the development of performance metrics" (Alegre & Coelho, 2012). Performance evaluation is now standard practice in the water sector, including water delivery and wastewater collection (Sadiq et al., 2010). The quest for improving productivity in the current global competitive environment has led to a need for rigorously defined performance-measurement systems for production processes. Absence of proper productivity measurement indicators locates manufacturing firms at an unknown production line performance (Amir, 2015). Therefore, constant assessment of production processes is essential to reveal the under-utilization of equipment, missed practices and losses.

Overall equipment effectiveness plays a vital role where performance and quality product are key, according to Vivek and Hemant (2014) in a review research on improving overall equipment effectiveness through total productive maintenance. Availability rate, a role in which product performance and quality are critical. When calculating OEE, the availability rate, performance, and quality rate are all taken into account. To improve OEE, Total Productive Maintenance was adopted as a foundation. The availability rate and quality rate were determined to have less of an impact than behind in the performance rate.
Pradeep et al. (2014) studied the implementation of total Productive Maintenance TPM to improve the overall efficiency and productivity of a news paper printing machine of a daily news paper company. Real-time data analysis was used to conduct empirical investigations. To analyze the success of TPM implementation in the industry, questionnaires were given out. The system's OEE was calculated. The average OEE is between 63 and 71 percent, compared to a world-class OEE of 85 percent. The findings revealed the primary factors that contribute to downtime and decreased productivity. Total productive maintenance has proven to be an effective strategy for increasing productivity and performance.

Naik et al. (2015) created and implemented a simulation model for OEE computation in a simulation model for overall equipment effectiveness of a generic production line. The input data for the model is obtained from XML files based on multi-criteria such as work-in-progress, inventory minimization, Idle-time minimization and application of theory of constraints. The front-end of the application model is implemented in visual-Basic and the simulation model is presented in MS-Excel

Mayur and Arun (2017), proposed the implementation of total production maintenance pillar to cut back losses related to OEE in medium scale industries. By minimizing cycle time, set-up time, break-downs, and other productive losses, the three aspects of OEE, namely availability, performance, and quality, are improved.

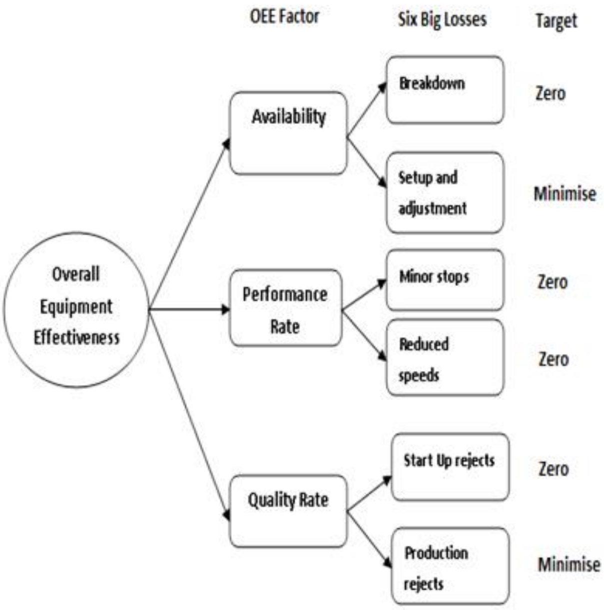

Figure 1. Overall Equipment Effectiveness model indicating the metrics and the six big losses (Verma & Dawar, 2014)

OEE can be used at numerous levels throughout the production process. It is a useful tool for benchmarking, analyzing, and improving your manufacturing process.
The OEE tool allows you to measure your machines' productivity and make improvements. OEE not only monitors inefficiencies, but also categorizes them into three categories to aid in machine analysis and a better knowledge of the manufacturing process. OEE is used to assess machine performance in terms of availability, efficiency, and quality, according to Nakajima (1998).
In a performance review using overall equipment effectiveness (OEE): an analytical tool, Mahmood et al. (2016) found that OEE impressed as a performance evaluation method for measuring the various forms of production losses (the six large losses) and identifying opportunities for improvement. It provides in-indepth visualization of OEE for manufacturing Equipment. The outcome of this assessment and performance monitoring, identified production-losses. The study concludes that analysing OEE reveals its potentials as a viable indicator of production losses. OEE can be used to optimize performance of existing capacity.

To improve efficiency in the manufacturing industry, Nallusamy and Gautam (2017) used a mix of total Productive Maintenance and overall equipment Equipment Effectiveness. The objective of the work is to inspect manufacturing losses by prioritizing root cause using pareto-diagram and suggesting how to overcome them. The result revealed a considerable reduction in set-up, break-down losses rework time and OEE increase by 15%.
Reliability is the probability of the equipment or process functioning without failure, when operated as prescribed for a given interval of time, under stated conditions. The term reliability as employed in the context of a power system has a wide range of implications, according to Popoola et al (2011). As a result, it is being discussed in two broad categories: system adequacy and system security.
Kumar and Saini (2018) developed a fuzzy reliability model for a marine power plant and analyzed the availability of the system using membership functions. Dahiya *et al.* (2019) developed and analyzed an A-Pan crystallization system used in the sugar industry. However, componentwise analysis of power plants has not been carried out so far in literature. Therefore, an effort is made herein to derive an expression for generators in power plants using a birth–death process and the supplementary variable

technique.

This research aim is to evaluate the operational losses using overall equipment effectiveness and also carryout reliability analysis in Bonny Island's water supply system.

The objectives of this research are:

i. To identify the operational losses and other wastages in the supply system for remediation.
ii. To determine the effectiveness of the Bonny water supply system using Overall Equipment Effectiveness.
iii. To carryout reliability analysis of the supply system in Bonny Island.
iv. To estimate Bonny town existing water supply and demand then compare the OEE to that of the world class system.

2. METHODOLOGY:

Bonny Water Distribution Plant (BWDP) comprises of five water treatment plants which are; Bonny Water Treatment Plant, Bypass Water Treatment Plant, Akiama Water Treatment Plant, Oguede Water Treatment Plant and Finima Water Treatment Plant. BWDP has a total capacity of 7.012 Million Liter per Day (MLD) for population of about 175000 people (according to Socio-Economic Implication of Nigeria Liquefied Natural Gas (NLNG) Project in Bonny Local Government Area, Rivers State, Nigeria). The average target and actual water supplied by the various water treatment plant are presented Table 3.

2.2. Availability

Availability compares a machine's or process' uptime to the projected production time. The availability of equipment is stated as a percentage as one of the variables of overall equipment effectiveness (OEE).

As an OEE statistic, availability takes into account all scheduled and unplanned stoppage. A 100 percent availability indicates that the production process is always functioning during the scheduled production time with no interruptions. It captures the events that stop planned production when the system is intended to be running.Mathematically ,

$$\text{Availability A} = \frac{SH - DT}{SL} \qquad (1)$$

where, A = Availability, SH = Shift Lenght, DT = Down Time

Another way availability can be measured is bye the use of availability indices, which include Mean Time Between Failure and Mean Time to Repair which can be expressed as

MBTF: The average time duration between successive failures within a useful life of a gas turbine. The following formulae are used to calculate MTBF:

$$\text{MBTF} = \frac{Total\ hours\ of\ operation}{Total\ number\ of\ failures} \qquad (3)$$

Mean time to repair (MTTR)

The average time taken to carry out the repair operation from the time failure commences to the time it is operational again. It is applicable to repairable equipment (The average time solely spent on the repair process is called mean time to repair.)

$$MTTR = \frac{Total\ hours\ of\ maintenance}{Total\ number\ of\ repairs} \quad (4)$$

Therefore, the availability is now defined as

$$A = \frac{MTBF}{MTBF + MTTR} \quad (5)$$

Availability captures two fundamental productivity losses;

i. Breakdowns. It involves all such as defects that calls for maintenance practices correct.

ii. Set-up and Adjustment. This refers to the disruption in production as a result of resetting of maintenance activities, clogging in the strainer, excessive vibration, bearing failure or mechanical seal failure.

2.3. Quality Rate

This is the percentage of good amounts produced out of the proposed amounts produced on the pumping machine is referred to as quality. The term "100% Quality" refers to the absence of any defects. The quality rate can be calculated using the following formula: (Chana et al, 2005).

$$Quality\ Rate = \frac{(target\ amount - Defect\ amount) \times 100}{Proposed\ amount} \quad (6)$$

Defect amount = Proposed amount – Actual amount of water supply. (7)

Quality takes into account "Defect Losses" from

i. Startup losses (pump required warm up time)

ii. Production losses (Not production according to specification).

2.4. Performance

The ability of equipment to generate goods is described by its performance ratio. The operational speed rate and net operating rate combine to produce this ratio. The difference between the ideal speed (determined by the equipment's design) and the actual operating speed is referred to as the equipment operating speed rate. The operating rate is the rate at which a given speed is maintained over time. In other words, it determines if an operation is steady over time when the equipment is running at a low speed. The formula for calculating this ratio is as follows:

$$Performance\ Rate = \frac{(Actual\ amt.of\ produced / Total\ operating\ time) \times 100}{Design\ capacity} \quad (8)$$

Performance takes into account Speed Losses from

i. Idling and Minor stoppages (Pump is stop< 10 min.)

ii. Reduced speed operation (Actual vs. design cycle time)

2.5. Overall Equipment Effectiveness (OEE)

The gold standard for measuring manufacturing productivity is OEE (Overall Equipment Effectiveness). Simply explained, it determines the amount of time spent in manufacturing that is genuinely productive.

An OEE score of 100% indicates that you are producing only good parts as quickly as possible with no downtime. That means 100 percent Quality (only decent parts), 100 percent Performance (as quickly as feasible), and 100 percent Availability in OEE terms (no stop time). OEE measurement is a best practice in manufacturing. The OEE can be written as:

$$OEE = Availability \times Performance \times Quality \quad (9)$$

World Class OEE

Table 1 shows the world class OEE with various OEE metrics. According to Afefy (2013) world class OEE is the yard stick which is used to compare measured OEE of a plant. It was introduced by Seiichi Nakajima in 1984 in his book titled Introduction to TPM.

Table 1: Percentage of world Class OEE

OEE Factors	World Class
Availability	90.0%
Quality	99.0%
Performance	95.0%
OEE	85.0%

There are six main losses in the water supply system which are called six big losses and they are grouped into three major categories: downtime, speed and quality losses. Table 2 show the six big losses in the water supply system and the goal of OEE is the reduce/eliminate the events that cause those losses in the supply system.

Table 2: Six big losses of water supply process

Six big losses category	OEE loss category	Event examples
Breakdowns	Downtime losses	• Fault in current • Trip • Pipe line leakages • Water shortages in sump well • Incorrect assembly of pump (improper alignment to pump & motor)
Setup and adjustments	Downtime losses	• Suction & Delivery valve • Open / close • Warm-up time • Tripped
Small stops	Speed losses	• Under design capacity • Suction & Delivery valve • Open / close • Warm-up time • Trip
Reduced speed	Speed losses	• Low water level in sump well • Frequency & Voltage fluctuation. • Oldest Pump/motor life reduce due to continuous running • Pump assembly parts life reduce and • Gate valve at suction & delivery side. • Operator inefficient

Start-up rejects	Quality losses	• Pipe line leakage • Leakage from • suction/delivery valve • Sump well leakage • Friction losses in entrance/exit vortices • Separation disc friction losses • Friction losses in pipe line
Production rejects	Quality losses	• Pipe line leakage • Leakage from • suction/delivery valve • Sump well leakage • Friction losses in entrance/exit vortices • Separation disc friction losses • Friction losses in pipe line

2.6 Reliability

This is the probability that a product or service will work efficiently for a given period of time (design life of product) under the design operational condition without failure. The mathematical function is written as follows:

$$Reliability, R(t) = 1 - F(t) \quad (10)$$

or

$$R(t) = \left(1 - \frac{DT}{EOH}\right) \times 100 \quad (11)$$

where ,
DT = Downtime
EOH = Equipment Operating Hours

3. RESULTS AND DISCUSSION:

Calculation of OEE

Using the average data of Bonny Water Treatment Plant BWTP

$$\text{Availability } A = \frac{SH - DT}{SL} \times 100$$

$$= \frac{724 - 49.6}{724} \times 100 = 93.16\%$$

$$Quality\ Rate = \frac{(target\ amount - Defect\ amount) \times 100}{Proposed\ amount}$$

$$= \frac{66448 - 13384.67}{66448} \times 100 = 79.86\%$$

$$Performance\ Rate = \frac{(Actual\ amt.\ of\ water/Total\ operating\ time) \times 100}{Design\ capacity}$$

$$= \frac{(53063.33/724) \times 100}{92} = 85.77\%$$

Ave OEE for BWTP = Availability × Performance × Quality

= 93.16 × 79.86 × 85.77 = 63.81%

$$Reliability = (1- \frac{DT}{EOH})\times 100$$

$$(1- \frac{49.67}{674.33})\times 100 = 92.63\%$$

The data in Table 1 comprises of two sets, the filtered and clean primary data that were given by Bonny Utility Company which comprises of number of failures, the evaluated operating times (EOH) and the downtimes, all considered on monthly basis. The primary data was also used to carry out various calculations to get the secondary data. The secondary data involved the MTTR, MTBF, Failure rate, Reliability and Availability, Quality, Performance, and **OEE.**

Table 3. Average data of various Water Treatment Plant (WTP)

Water Treatment Plants	**Bonny Water Treatment Plant**	**Bypass Water Treatment Plant**	**Akiama Water Treatment Plant**	**Oguede Water Treatment plant**	**Finima Water Treatment Plant**
Shift Length (hr)	724	724	724	724	724
NOF	4.833333	3	3	2.166667	6.333333
DOWNTIMES (hr)	49.66667	31.5	54	36.66667	233.2667
EOH (hr)	674.3333	692.5	670	687.3333	490.7333
Target water (m3)	66448	35256	39632	24400	49600
Actual (m3)	53063.33	30756	34193.33	20831.67	34310.17
Defect (m3)	13384.67	4500	5438.667	3568.333	15289.83
AVE DESIGN CAPACITY OF PRODUCED (m3/hr)	92	58.66667	56.66667	35	90
MTBF	175.3787	282.9306	301.8917	375.9167	99.03981
MTTR	10.53241	12.73611	18.10833	18.08333	43.96019
FAILURE RATE	0.007214	0.004296	0.004528	0.003189	0.013331
RELIABILITY	0.926347	0.954513	0.919403	0.946654	0.486682
AVAILABILITY	0.931579	0.956526	0.926457	0.949142	0.678368
QUALITY	0.798569	0.872362	0.862771	0.853757	0.691737
PERFORMANCE	0.857714	0.758049	0.900693	0.867645	0.788871
OEE	0.63808	0.632544	0.719942	0.703085	0.37018

Table 4: OEE values of the various WTP compared to the world standard

	Bonny Water Treatment Plant	Bypass Water Treatment Plant	Akiama Water Treatment Plant	Oguede Water Treatment plant	Finima Water Treatment Plant	Total Average	WORLD CLASS OEE
AVAILABILITY	0.931579	0.956526	0.926457	0.949142	0.678368	0.888415	0.9
QUALITY	0.798569	0.872362	0.862771	0.853757	0.691737	0.815839	0.99
PERFORMANCE	0.857714	0.758049	0.900693	0.867645	0.788871	0.834595	0.95
OEE	0.63808	0.632544	0.719942	0.703085	0.37018	0.612766	0.85

3.1. Monthly reliability diagram of the various water treatment plants.

The result for the reliability analysis carried out on the various WTP is represented in Figure 2.

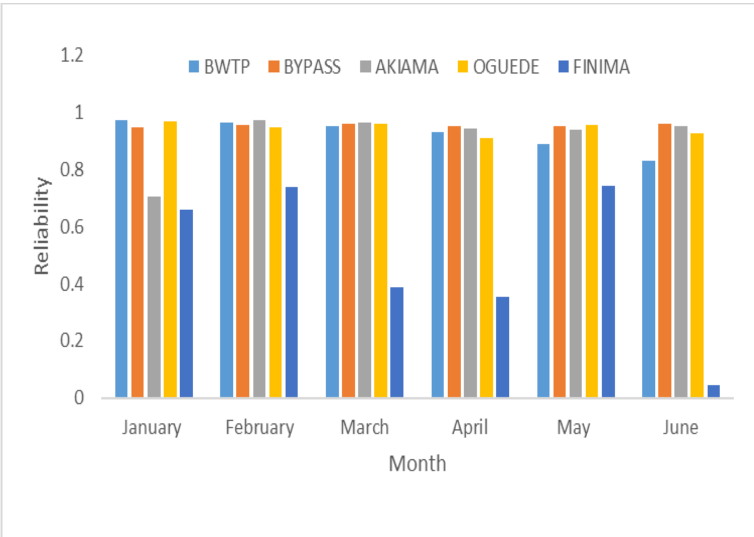

Figure 2: Variation in monthly reliabilities of the various WTP

Figure 2 show the variation in monthly reliability of the various water treatment plants, it shows that Bypass maintained almost steady reliability at 99.18% while Finima and BWTP decreased significantly as the time goes with average reliability of 90.46% and 95.48% respectively. We can see that Finima is the least reliable amongst the various water treatment plants.

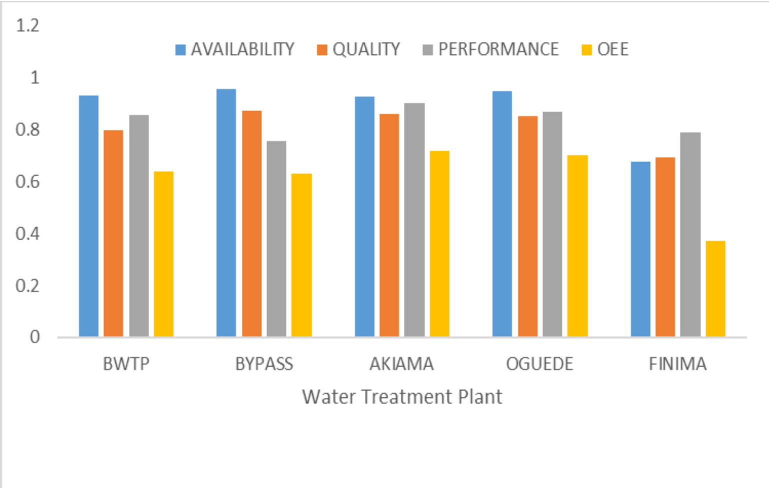

Figure 3: OEE of various water treatment plant

The Figure 3 represent the OEE of various water treatment plant of the Bonny Water Distribution System. From the graph we can deduce that the underperforming WTP is FINIMA with the least OEE and OEE matrices value while the best performing WTP is OGUEDE with best OEE value.

3.1. Comparison of the measured OEE to the world standard

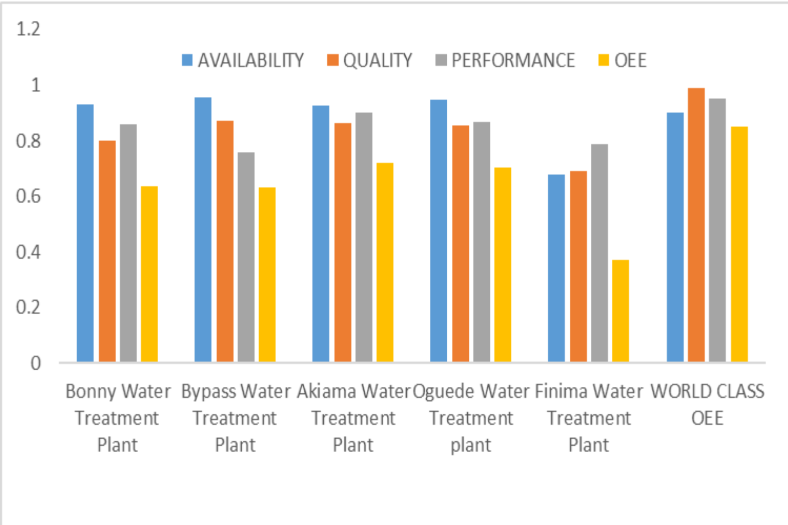

Figure 4: Comparison of measured OEE to the word standard

Figure 4 shows the average OEE and OEE metrics of the various WTP as compare to that of the world class system. We can see that all WTP except Finima WTP met only the availability requirement of the world class system.

The consequences of the six big losses and their events as presented in Table 2 is that they can result to either downtime or water loss. Figures 5 and 6 show the downtime losses and amount of water losses of various water treatment plant.

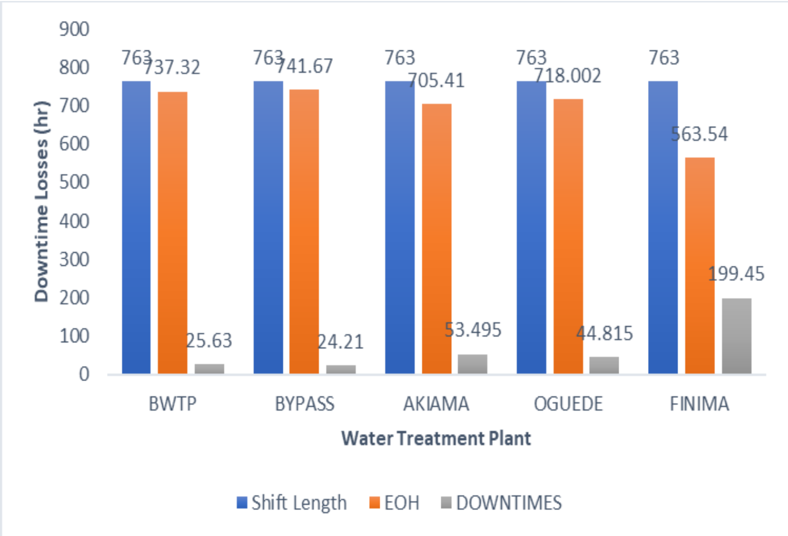

Figure 5: Downtime losses of various WTP

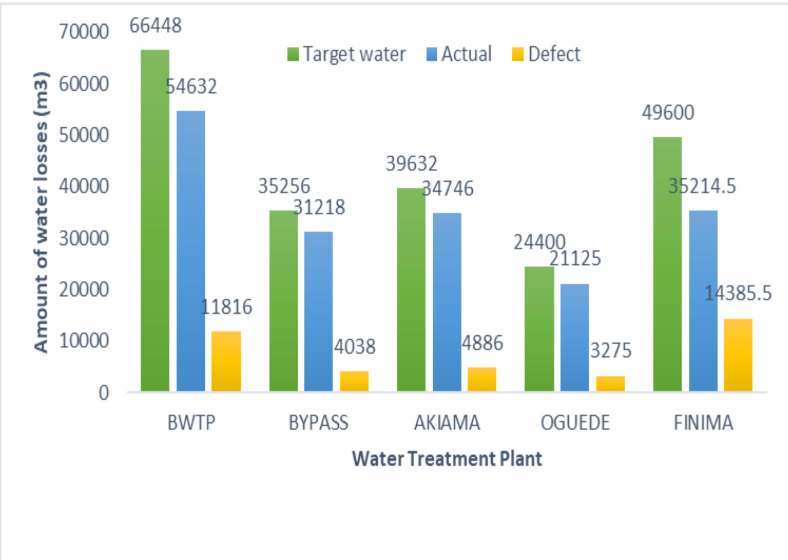

Figure 6: Amount of water losses of various WTP

CONCLUSION:

The research identified the main sources of operational losses and wastes, which include downtime, speed, and quality losses, all of which have an impact on OEE. To reduce these losses and attain world-class OEE, the events that causes the six main losses should be reduced. Some of the events that cause losses in the water supply process include, faults in current, trips, pipe line leaks, water shortages in sump wells, wrong pump assembly (improper alignment to pump & motor), and operator inefficiency.

Secondly, the Overall Equipment Effectiveness of the Bonny Water Distribution Plant was also carried out and it was observed that the average OEE of water supply systems in BWDP is 61.28 percent, while world-class OEE is 85 percent or better.

Also, analysis of the various treatment plants were considered and it was observed that Bypass and Oguede water treatment plants maintained almost steady average reliabilities at 95.55% and 94.6% for the period considered in the research while the reliability of Finima decreased significantly as the time goes with average reliability being 48.67%.

RECOMMENDATION:

This study chose the topic of OEE and Reliability and conducted a thorough investigation.
A series of recommendations was proposed based on the theory investigated and analyzed in order to improve the OEE and hence increase the water supply and availability. Those recommendations include: controlling extraneous leaks, increasing water supply and storage capacity, reducing the number of joints in pipe lines, laser alignment of pump and motor, maintaining sump well level (water level), pump refurbishment work on a regular basis in accordance with the maintenance schedule, and performing preventive maintenance on a regular basis. Pumps and their drivers should also be examined on a regular basis in accordance with maintenance plans. In addition, to limit the amount of issues and pipeline leaks.

REFERENCES:

Adegboyega, G. A., & Famoriji, J. O. (2011). Determination of the Central Gas Turbine Efficiency and Reliability, Edjeba, Delta State, Nigeria. *International Journal of Engineering Research and Technology*. 2(1),482–490.

Achara, O. M. & Godwin, C. (2013). Optimum Maintenance Strategy for Paint, Manufacturing Industries, A case Study, *International Journal of Advance Engineering Research and Studies* 3 (1), 123 - 130.

Alegre, H. & Coelho, S.T. (2012). Infrastructure Asset Management of Urban Water Systems, in "*Water Supply System Analysis - Selected Topics*". In: Ostfeld, A. (Ed.), InTech, ISBN: 978-953-51-0889-4, In Tech. Available from: http://www.intechopen.com/books/water-supply system-analysis-selected topics/infrastructure-asset-management-of-urban-water-systems.

Amadi, A. N. (2011). Assessing the Effects of Aladimma Dumpsite on Soil and Groundwater Using Water Quality Index and Factor Analysis. *Australian Journal of Basic and Applied Sciences*, 5(11), 763–770.

Amir, A. (2015). Evaluation Improvement of Production Productivity Performance Using Statistical Process Control, Overall Equipment Effectiveness and Autonomous Maintenance, *Procedia Manufacturing*, 2 (1), 186 - 190.

Chetan, P., & Vivek, D. (2016). A Review on Improvement in Overall Equipment Effectiveness, *International Journal for Research in Applied Science and Engineering Technology*, 4(11), 642-650.

Dahiya, O., Kumar, A. & Saini, M. (2019). Mathematical Modeling and Performance Evaluation of a-Pan Crystallization System in a Sugar Industry, *Springer Natures Applied Sciences*. 1(4), 339 - 348.

Kumar, A. & Saini, M. (2018). Fuzzy Availability Analysis of a Marine Power Plant. *Materials*

Today: Proceedings. 5(11), 25195-25202.

Mayur, M. M., & Arun, K. (2017). A Review on Employment of TPM to Improve OEE in the Manufacturing Industry. *International Journal of Innovative Research in Science, Engineering and Technology*, 6(8), 2319-2347.

Muhammad, A. S., Muhammed, R. H., & Asrafuzzaman, S.A. (2012). Analysis of performance by overall equipment effectiveness of the CNC cutting section of a shipyard, *Journal of Science and Technology*, 2(11), 1091-1096.

Naik, R., Raikar, V.A., & Naik, G. (2014). A simulation model for overall equipment effectiveness of a generic production line. *Journal of Mechanical and Civil Engineering*, 12(5), 52-63.

Nakajima, S. (1988). *Introduction to TPM: Total Productive Maintenance (preventative maintenance series*), Productivity Press.

Nallusamy, S., & Gautam, M. (2017). Enhancement of overall equipment effectiveness using total productive maintenance in a manufacturing industry. *International Journal of Performability Engineering*, 13(2), 1-16.

Nwankwoala, H. O. (2010). Electrical resistivity survey for groundwater in Egwede, Andoni Local Government Area, Rivers State, Nigeria. *(In Press)*.

Pardeep, G., & Sachit, V. (2016). Optimizing OEE, productivity and production cost for improving sales volume in an automobile industry through TPM: a case study, *International Journal of Production Research*, 54(10), 2976-2988.

Pradeep, K., Raviraj, S., & Lewlyn, L.R. (2014) Overall equipment efficiency and productivity of a news paper printing machine of a daily news paper company - A Case Study" *International Journal of Engineering Practical Research* , 3 (1), 1-8.

Popoola, J. J., Ponnle, A. A., & Ale. T. O. (2011). Reliability worth assessment of electric power utility in Nigeria: residential customer survey results. *Assumption University Journal of Technology*. 14(3), 217–224.

Sadiq, M., Rahmani, M., Ahmad, M.W., & Jung, S. (2010). Software risk assessment and evaluation process (SRAEP) using model based approach. *2010 International Conference on Networking and Information Technology*, 20(1) 171-177.

Verma, D.S., & Dawar, R. (2014). Measurement of Overall Equipment Effectiveness for Water Discharge System: A Case Study. *International journal of engineering research and technology*, 3(4), 737-743.

Vivek, M., Karthick, R., & Dr. Senthil Kumar, G., (2014). Optimization of overall equipment effectiveness in a manufacturing system. *International Journal of Innovative Research in Science, Engineering and Technology*, 3(3), 1192-1196.