Evaluating the Impact of Total Productive Maintenance elements on a Manufacturing Process

Mthetheleli Joseph Kwaso
Post Graduate School of Engineering Management
University of Johannesburg, South Africa
jsphmahlatsi@gmail.com

Arnesh Telukdarie
Post Graduate School of Engineering Management
University of Johannesburg, South Africa
arnesht@uj.ac.za

Abstract

Variety of Process improvement tools exist; with each having a similar goal which is to enhance the performance of the business. Total Productive Maintenance (Total Productive Maintenance) is not only a maintenance strategy, but also a business improvement tool that companies use to remain competitive whilst improving customer's satisfaction and reliability.

The purpose of this research is to understand the impact of the TPM elements and their performance roles on the facility as a whole.

A South African manufacturing firm in the process of implementing TPM is studied, to assess the progress made during the implementation process and the learnings that come with it. The data collected before and after TPM implementation at the company used in this case study is used to calculate the availability, performance efficiency, quality rate, and the overall equipment effectiveness (OEE).

The result showed that OEE consistently improved its value above Eighty percent (80%) from implementation. This improvement indicates the TPM pillars capability in enhancing business, underpinning these elements as crucial for a successful implementation.

Keywords: TPM (Total Productive Maintenance), OEE (Overall Equipment Effectiveness), Maintenance Strategy, Business Improvement, Manufacturing

1. Introduction

Most manufacturing processes are not cost effective in operation and support, this is due to low running capacities that result in low productivity and manufacturing costs escalation (Sandelands, 1994). One of the contributing factors to this negative outcome is ineffective maintenance practices on the plant equipment. Maintenance practices ensure that the plant is available to operate, safe to work in, produces right product quality, and cost effectiveness. Maintenance costs constitutes a significant portion of the operating budget of companies in the manufacturing sector (Tsarouhas, 2007). TPM as a philosophy is therefore a collection of practices and techniques that aims at maximizing the effectiveness of business facilities and processes where all are responsible. A Variety of process improvement tools exist with each of these having a similar goal, that improves the performance of the business. Process improvement tools include but are not limited to Total Quality Management (TQM), Lean manufacturing, Six Sigma, Business process re-engineering, International Organization for Standardization(ISO) and Total Productive Maintenance (TPM). TPM is therefore not only a maintenance strategy, but a business improvement tool that companies can use to remain competitive and improve customer satisfaction, and reliability.

The methodology or philosophy of TPM is implemented through basic practices known as TPM elements (Pillars). These pillars include Housekeeping (5S), Autonomous Maintenance (AM), Kaizen, Planned Maintenance, Training, Office TPM, Safety Health and Environment, (Wakjira and Ajit, 2012).

The purpose of this research is to understand the impact of the TPM elements on the implementation process. It will further help to identify the roles played by each of the pillars on the performance of the philosophy as a whole. The benefits of TPM implementation have been visible at various plants which have taken on the philosophy. Companies that are successful in adopting TPM have reported a reduction in breakdowns, lost production, setup time requirement, cost per maintenance unit, and lastly capacity increment (McKone, Schroeder, and Cua, 2002). A considerable number of companies have failed in adopting TPM, which failure has been attributed to difficulties faced in implementing TPM that include, lack of management support and understanding, lack of sufficient training and failure to allow sufficient time for evolution (Kocher, Kumar, Singh, and Dhillon, 2012).

1.1 Components of TPM

In order to achieve sustainability, efficiency and effectiveness of the manufacturing facility by the TPM team, seven (7) practical components and activities centred on people involvement and enhancement becomes necessary.

5S (Sort, Set in Order, Shine, Standardize, and Sustain)

This constitutes the best way to organise and manage workspace and eliminating wastes through better thoughts and focus. It provides and improves maintenance systems to support the facilities. The successful execution of TPM requires the adoption of 5S at the preparatory stage of the philosophy, giving it enough attention. Originating in Japan in 1982, 5S concept achieved substantial results in industrial and service sectors. It aims at preventing losses, with achievable result of safety incidents prevention, delays reduction, and enhanced productivity, (Nilipour, and Jamshidian, 2005). According to Tsarouhas (2007), failing to take 5S seriously leads to 5D (Delays, Defects, Dissatisfied customers, Declining profits, and Demoralized employees). For 5S to be successful the major contributing factor is the active participation by the staff in all 5S related activities, and also important to the sustainability of 5S is proper training for the staff on the concept of 5S and its importance so that each personnel may understand the significance of the role he/she needs to play (Moradim, Abdollahzadeh, and Vakili, 2011). According to [10] implementing 5S accurately and properly forms a foundation for the implementation of TPM.

Figure 1.Practical Components of TPM (Source: lecture 2004)

Restore, maintain and continuously improve the existing facilities

This includes the role of both maintenance and operation personnel to monitor effectiveness of the machines, inspect points, analyse breakdowns, carry out preventive maintenance, major repairs, and to maintain basic conditions to prevent deteriorations.

Detect and eliminate faults and problems

Early detection and elimination of faults devoid the following: Slow the process down, cause inconsistency, rejects, safety hazards, make machinery dangerous to operate, make work place dirty, oily and smelly.

Establish, monitor and improve process effectiveness

Notably, this aids in reduction, recognition and measure of the 6 big losses attributed to availability, performance and quality: breakdowns losses due to failures, speed, idling, minor stoppage, start-up losses scrap and rework losses.

Identify and eliminate inherent faults

The need to discover either inherent design and manufacturing of machinery faults and that attributed to operational methods with a provision for proposing a project with a skilled small team to focus on inherent faults to improve overall effectiveness.

Purchase and install facilities that provide best return

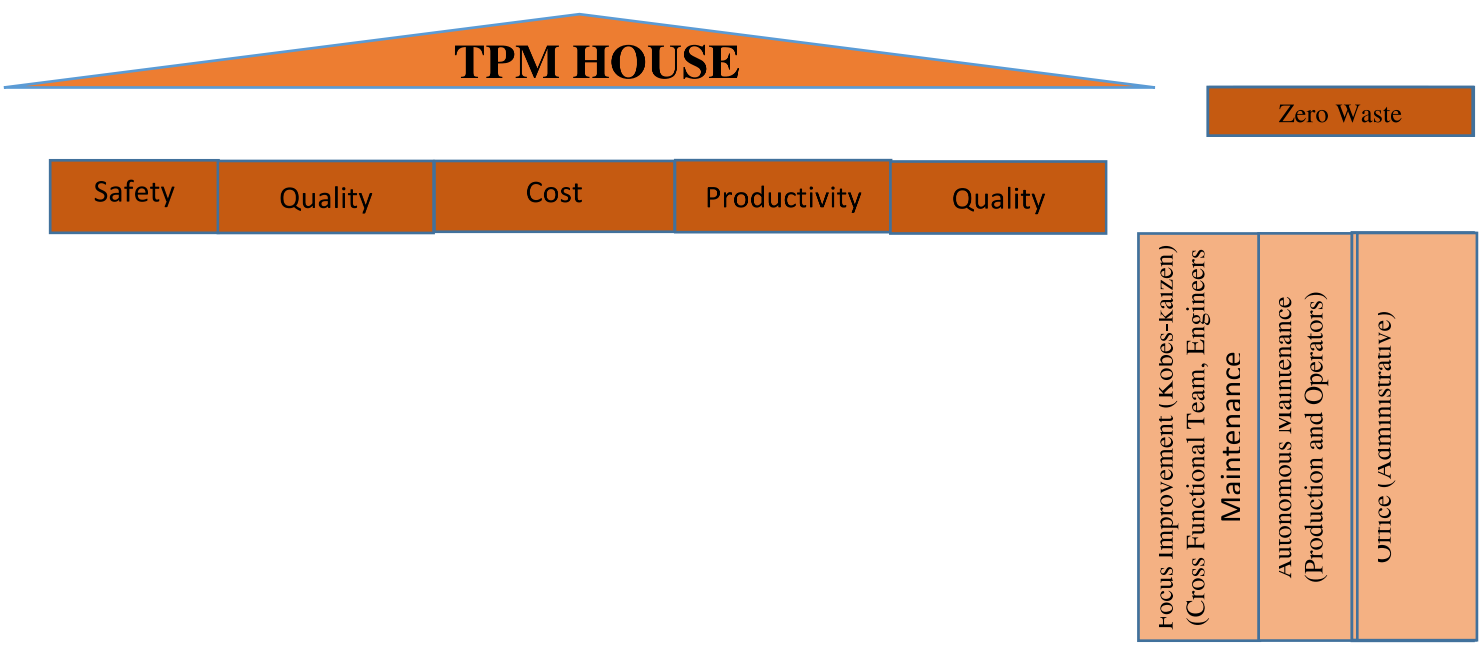
This component states that selection of manufacturing machines must conform with the TPM philosophy in a professional and structured way to meet the present and future need of the business and to achieve global competitive performance.

1.2 TPM pillars

These are ways of managing change and a rigorous methodology to sustain common future. It is the change streams responsible for the development of systems, processes, capabilities and standards with People. It applies appropriate problem-solving techniques to form a unified and cohesive structure that spans both levels and functions to achieve common purpose (Sandelands, 1994). These elements constitute key measures for operation and maintenance and employs elimination of failures, zero defects, zero accidents, zero Break-downs, no wastes and loss (Campbell, and Reyes-Picknell, 2006).

Autonomous Maintenance

Autonomous Maintenance is based on assigning operators the responsibility of minor maintenance activities required to keep the plant equipment in the best shape possible, and this will give the specialized maintenance staff more time to attend to issues that are more complex (Wakjira, and Ajit, 2012). In Kocher, et al. (2012) Autonomous Maintenance and Focused Improvement Pillars of TPM is carried out in a big volume beverage bottling plant which results of this implementation showed closely how much of an impact it had on the organisation. With the involvement of employees across all levels of the organisation, teams were formed which were responsible for executing all the tasks required for the successful implementation of these two pillars. To better understand the changes brought about the implementation of these pillars, Kocher, et al. (2012) calculated the OEE using data collected over a period of six months from varying sources that include maintenance records, production personnel, and daily production data. According to Kocher, et al. (2012) the successful implementation of the Autonomous Maintenance pillar and Focused Improvement showed an improvement in the production output indicated by the OEE rising from 75,17 % to 85,25 % with no customer complains and zero accidents among other improvements resulting from the implementation of these two pillars.



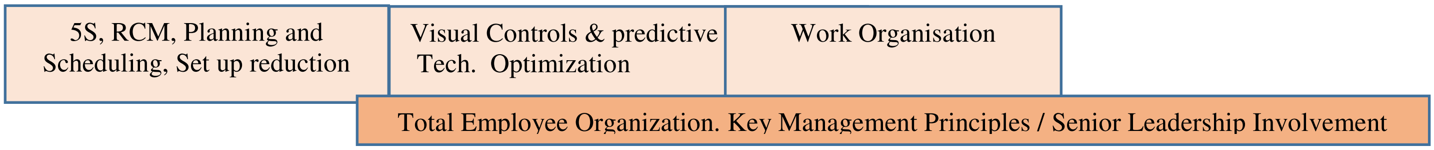


Figure 2:Pillars of TPM(Source. Author adapted from [7])

Focused Improvement/Kaizen

According to. Kocher, et al. (2012), Kaizen is the third step in TPM implementation, and the word Kaizen is derived from two Japanese words 'Kai' and 'zen' meaning change, and better or good respectively. This tallies, with the definition from (Eti, Ogaji, and Probert, 2004) meaning "continuous improvement" or "change for the best". Kaizen according to Wakjira, and Ajit, (2012) delivers minor improvements continuously in the organisation where all staff partake, achievable through little or no monetary investment but through Kaizen tools systematic programs. Kaizen enhances TPM goal by maximizing the equipment effectiveness, attempting to eliminate all losses through its activities (Mehta, Singh, Gohil, Shah, and Desai, 2003). Notable six major losses damaging to the progress of production systems according to Ahuja and Khamba, (2008) are equipment failure losses, adjustment losses, idling and minor stoppage losses, defect and rework losses, and start-up losses.

Planned Maintenance

This pillar aims to ensure that the equipment does not breakdown frequently, and that customers' expectations are met by supplying them with good products and just in time. Maintenance grouped into four according their functions which are Preventive maintenance, Breakdown maintenance, predictive maintenance and corrective maintenance. Planned maintenance brings about a proactive culture towards maintenance and supports the autonomous maintenance pillar, by enforcing training for operators by skilled maintenance individuals so that they are able to maintain their equipment (Mehta, et al, 2015). Specifically, planned maintenance aims for zero equipment failure and breakdowns, and the improvement of reliability and maintainability by 50% and the reduction of maintenance costs by 20% (Wakjira, and Ajit, 2012). During TPM implementation the maintenance department allocate more time and resources to carrying out preventative maintenance duties. The implementation of autonomous maintenance will assist in this regard as machine operators will carry-out basic maintenance tasks thus affording the maintenance staff more time to focus on more challenging issues as listed on the maintenance schedule (Thun, 2006).

Quality maintenance

The objective of the Quality Maintenance (QM) Pillar is to satisfy the customers through consistent supply of products that meet their specifications, without defects (Wakjira, and Ajit, 2012). The pillar aims to lower in-process defects, and ultimately achieve a zero defect target (Ahuja, and Khamba, 2008). Vardhan, Gupta, and Gangwar (2015) single out the QM as one of the most critical amongst the other pillars; ensuring productivity improvement and customers' satisfaction. The execution of this pillar is very systematic and similar to focused improvement. Once the equipment and its parts causing defects, are identified it is safeguarded to prevent any further damage to the product quality. This pillar addresses other concerns potential to hinder the required quality targets (Wakjira, and Ajit, 2012). Vardhan, et al (2015) closely monitored the performance of the QM after the implementation of all the TPM pillars. The QM pillar was in this case tasked with achieving certain targets, that includes elimination of packaging defects, elimination of customer complaints and the elimination of product defects as these were the three quality issues that the company was predominantly faced with prior to its implementation.

Training and Education

Workforce is a priceless asset which systematic training can be tailored according to needs. Training analyses is done in accordance with the department need and availability of resource. According to [26] the training and development improve the employee skill, morale, and expertise. It elevates performance at to the highest level of efficiency and dedication. In (Kocher, et al., 2012) studies show TPM implementation and the challenges attributed with this process, and unpins it as the most important step in TPM implementation. This TPM element encourages the personnel specialisation, multitasking and multi skills devoid of inexperience in the execution of duties (Kocher, et al., 2012).

Safety, Health and Environment
This creates a workable safe healthy area minimal environmental damage resulting from organisational processes and procedures. Safety is at the top of the priority list in the plant environment. If properly implemented it achieves zero accidents, zero health damages and zero fires (Mehta, et al., 2015). The success of this element depends on 6 factors identified in Fernández-Muñiz, et al., (2009) Implemented correctly this pillar results in a number of both direct and indirect benefits; lower insurance premiums, fewer accidents, less damages and lower medical and legal costs, overall company's good performance indicated by its higher productivity and efficiency, good products quality and a better image enhancement. Negligence of this TPM element results to unsafe workplace; accidents, morale and motivation deterioration, and poor customer and public relations, (Fernández-Muñiz, et al., 2009).

Logistics and Office Administration
This pillar is interlinked with the other TPM elements but centred on people a reduction of waste. It is all about work organisation and leadership involvement, implementation of and management of the company's rule, staff warfare, motivation, code of conducts and ethics. If implemented correctly this pillar result in a number of benefits.

Early Equipment and Product Management
This TPM pillar is grouped into two parts: early equipment and early product management. It aims to implement new products and processes with vertical ramp up and minimised development lead time incorporating improvements into the next generation of product and equipment design. While the first group ensures minimal equipment downtime (zero breakdowns) by introducing a loss and defect free process, considering optimisation and maintenance costs from commissioning onwards, (Owen, 2014). The role of early product management with teams working on simultaneous activities is to shorten development lead times, so that vertical start up can be achieved with zero quality loss (zero defects).

1.3 OEE Concept
TPM uses the Overall Equipment Effectiveness (OEE) to measure both the performance of productive systems and degree of implementation success. The main objective of TPM is to improve the OEE, (Ahuja, and Khamba, 2008) which strength lies in the detection of losses and it highlights areas that need to be improved upon. OEE has not only developed as a backbone of the TPM philosophy but also of other techniques employed in asset management programs such as lean manufacturing, six sigma and world class manufacturing (Iannone, and Nenni, 2013). OEE is calculated by obtaining the product availability of the equipment, performance efficiency of the process and the rate of quality of the products (Dal, Tugwell, and Greatbanks, 2000). TPM has standards of 90 percent availability, 95 percent performance efficiency and 99 percent rate of quality (Levitt, 1996). An overall 85 percent benchmark is considered as a world class performance (Õrjan, 1998).

2. Case Study
The unit of analysis is defined as a basis for the case, which may be an organisation, a team or a department within an organisation (Kruger, and Welman, 2002). The unit of analysis used for this research is a South African manufacturing firm, which supplies packaging products to beverage companies across Africa. The case in question is currently in the process of implementing TPM in one of its biggest plants in South Africa. The TPM implementation kicked off in the beginning of 2017. The research studies the impact that the TPM pillars have on the implementation and the manufacturing process. To allow the researcher to study the impact of each of the elements on the implementation process closely, and on the manufacturing process, its processing plant is studied.
Prior to the current implementation of TPM in the plant some TPM elements were partially practiced in the plant. These include planned maintenance, quality maintenance, autonomous maintenance and 5S principles, therefore suggesting that TPM had been implemented previously. The practice of the mentioned TPM elements were not bringing the desired results and this led to the re-implementation of the process as a whole to try and address the current business challenges. Data is collected mainly for the first 8 months of the year January to August, where January to May was used as a baseline for the research. During this period the implementation was not carried out in full from June to August some practices were consistent, that will be analysed further.

The research focused on the implementation process, and assessing the impact that the implemented pillars have on the following Key Performance Index (KPI):

- **Downtime:** Downtime data will enable us to calculate the availability, and so asses the effectiveness of the implementation of the autonomous maintenance pillar.
- **Quality:** Process defects resulting from the manufacturing process under study will be recorded, and used to calculate the quality rate. Data obtained from quality rate calculation the role played by the quality maintenance pillar and related quality control measures will be assessed.
- **Productivity:** Productivity data will be collected and used to calculate the performance efficiency. The performance efficiency will indicate the degree to which the process is being effectively utilized. With the analysis of the performance efficiency, the impact of the focused improvement efforts will be assessed which aimed at improving the process continuously.

2.1 TPM Implementation

The implementation began with a TPM kick-off meeting which was held to officially launch the program, this was done in the presence of the entire staff and other Stakeholders. After the kick-off meeting training programmes were rolled out in the form of boot camps, to encourage teamwork and to familiarise the staff with the philosophy of TPM. The training was also practical as the participants were involved in activities that aimed to demonstrate how the first set of pillars which are visual management (VM), 5S, autonomous maintenance and focused improvement will be implemented in each work area. Following the training the first set of pillars were rolled out in different work stations.

One of the short-falls of the previous implementation, was the lack of active participation in sustaining the pillars and ensuring that the process is continuous and it ultimately becomes a day to day culture and the way people work. Also lack of management support and involvement on day-to-day challenges relating to the process, paying attention mostly to major breakdowns but not to the issues which could potentially lead to these breakdowns. Active participation among employees from different departments in all TPM related activities is essential for the success of the program.

The current implementation encourages participation from all employees through the use of GEMBA walks. The walks take place three times a week, and every area has a GEMBA team that is composed of production staff, maintenance, admin and management. Every area has a Visual Management (VM) board that shows the one point lessons (OPLs), 5S journey, high risk areas, top 3 losses of the area and the Kaizen projects implemented to get rid of the losses, and lastly KPIs such as downtime, spoilage and quality associated with the area.

3. Results

This section presents the results obtained following the collection of data. The unit of analysis houses three manufacturing lines, and for the purpose of this research a processing plant in one of the three lines is studied closely, and relevant data was collected. The researcher will look closely at KPIs such as the downtime which will be used to calculate the availability. The quality rate and the performance efficiency are also calculated to obtain the OEE. This allows for tracking the progress made as a result of the TPM implementation.

Downtime

Downtime losses are among the six big losses contributing to production process running at low efficiencies. The data collected includes electrical and mechanical breakdowns, unplanned and planned maintenance, general equipment failure and any set-up and adjustment. The strategic outcome of implementing TPM is the minimal occurrence of sudden machine breakdowns that get in the way of production and result in losses (Ahuja, and Khamba, 2008). Below figure 3 presents the downtime data for the 8 months, where red is before implementation and green is after implementation.

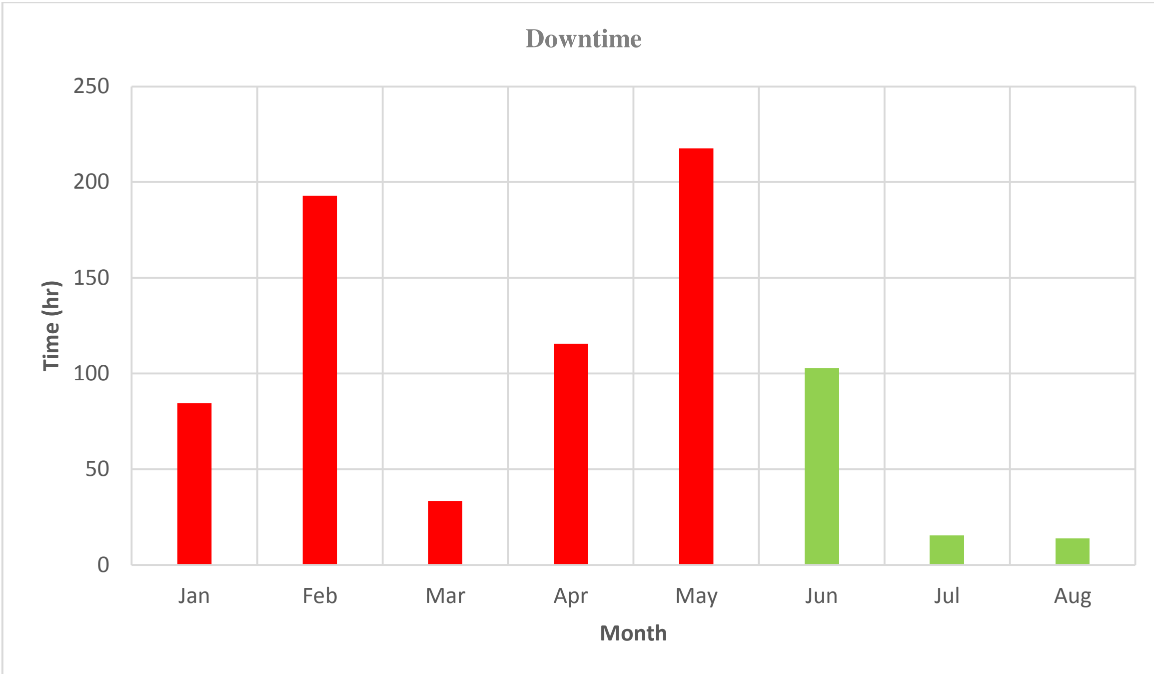


Figure 3:Downtime Data

Although the implementation is new positive results are starting to show, with the highest losses after implementation in June at 102,81 hours a significant improvement from a peak of 217,6 hours before implementation. Another positive is that in July and August not only were the downtime losses at their lowest at 15,5 and 13,7 hours respectively.

Availability

Using the downtime data collected the availability was calculated for each month using the following equation:

$$Availability\ (A) = \frac{Net\ loss}{Total\ good\ hrs} \times 100$$

where the: Net loss= Total good hrs – Total loss

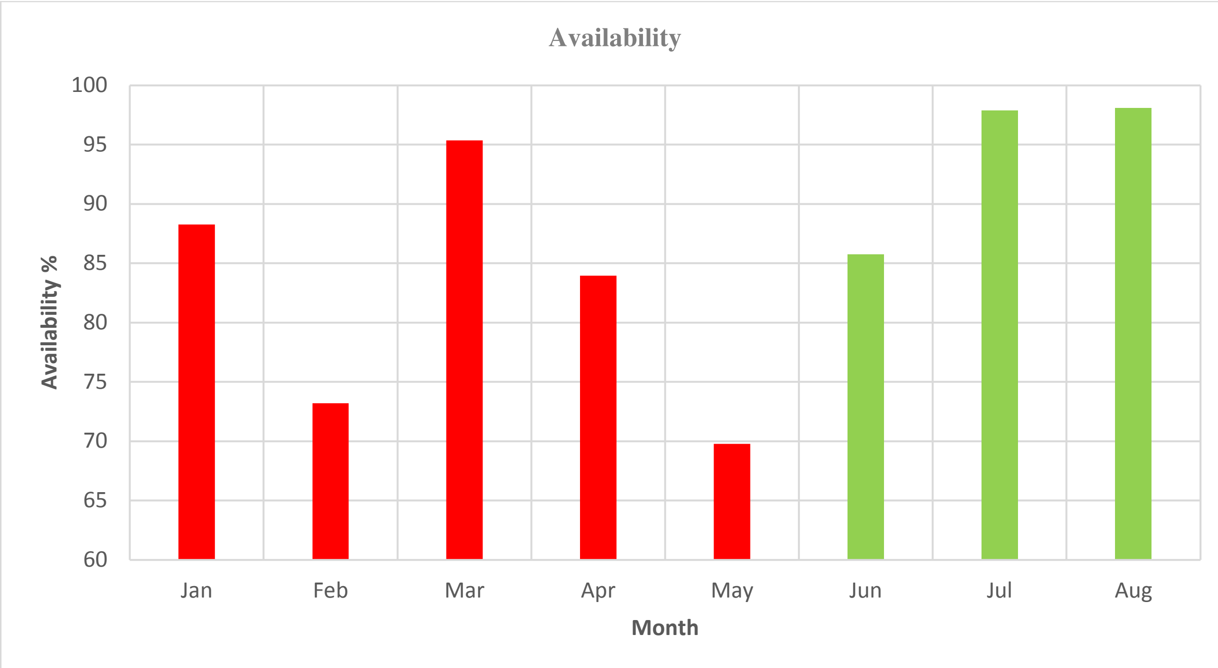


Figure 4: Availability data

According to (Levitt, 1996) TPM has standards of 90% availability for a plant to be considered a world class manufacturing facility. Figure 4 above shows how difficult it has been to achieve this value consistently, being achieved only in March before implementation when the availability was 95,3%. In May the availability was at its lowest at 69,8%. After the implementation in the three months recorded the lowest availability value was 85,7% obtained in June an improvement from the 69,8% obtained in May and closer to the world class manufacturing benchmark of 90%. Availability saw a significant improvement in the month of July and August at 97,9% and 98,1% respectively.

Quality Rate

The quality rate was calculated using the equation below:

$$Rate\ of\ Quality\ (Q) = \frac{Processed\ units - Defective\ units}{Processed\ units} \times 100$$

Table 1: Quality rate

Month	Quality Rate
January	99.87
February	99.84
March	99.90
April	99.68
May	99.75
June	99.89
July	99.87
August	99.77

The rate of quality or the quality rate is an important KPI in manufacturing, as it allows us to track the number of defects that have resulted from the manufacturing of good products. A reduced yield and defects in a process form part of the six big losses, which if not eliminated or controlled can cost the company millions of Rands. Table 1 above presents the results of a calculation of the quality rate before and after the implementation of TPM at the unit of analysis. According to [14] the world class manufacturing standard for the rate of quality is 99%. As it can be seen from table 1, the quality rate has consistently been above the 99% before and after implementation.

Performance Efficiency
The performance efficiency was calculated using the equation below:

$$Perfomance\ Eff\ \ (P) = \frac{Net\ loss - [Management\ loss + Startup\ loss]}{Net\ loss} \times\ 100$$

Where the: $Net\ loss = Total\ good\ hrs - Total\ loss$

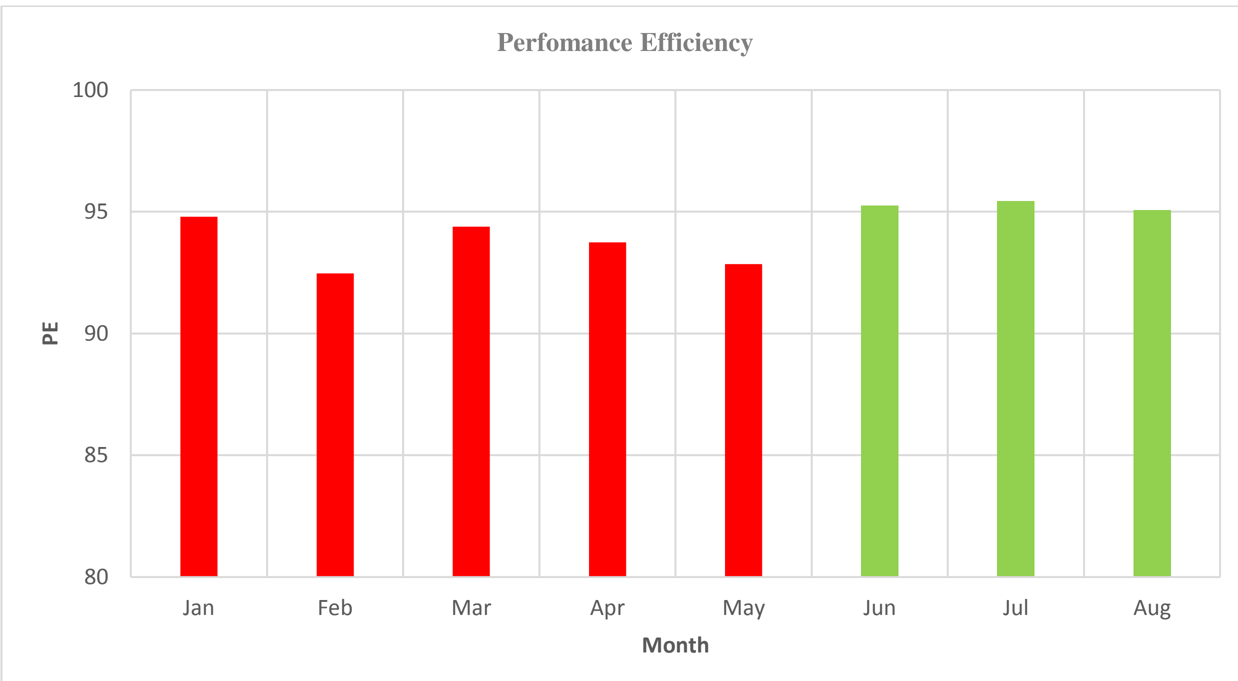


Figure 5: Performance Efficiency data

Idling and minor stoppage form part of the six big losses, and they impact the performance efficiency directly. The performance efficiency world class manufacturing benchmark is set at 95% (Levitt, 1996). This target has not been reached before implementation, as indicated by figure 5 above. Although the 95% target has not been reached before implementation, the results indicate that the plant in question has come close to achieving this target month after month. With the lowest performance efficiency value at 92,5% in February and the highest 94,8% in January. The target was reached in every month after implementation.

OEE
Now that we have obtained the availability, quality rate and the performance efficiency we can proceed to calculate the OEE using the equation below:

$$OEE = Availability\ (A) \times\ Perfomance\ Efficiency\ (P) \times\ Rate\ of\ Quality\ (Q)$$

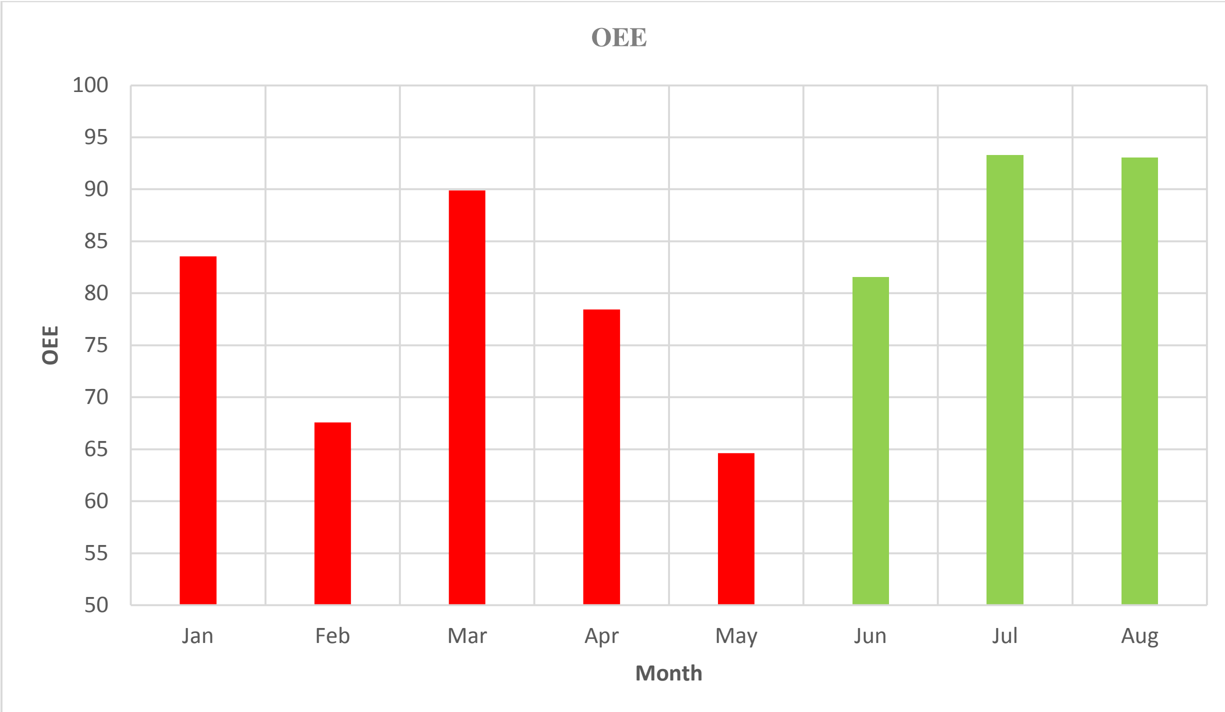


Figure 6: OEE data

TPM uses OEE to measure the performance of productive systems and again as a measure of the success of its implementation. The main objective of TPM is to improve the OEE (Ahuja, and Khamba, 2008) The world class performance benchmark for the OEE is 85% (Õrjan, 1998). This value is reached only once before implementation with the OEE value of 89,9% in March as shown in figure 6 above. The lowest values of the OEE before implementation were in February and May at 67,6% and 64,6% respectively. With the implementation we start to see a difference in the OEE. Firstly, in the three months of the implementation the lowest value is 81,5% as shown in figure 6 above, which is higher than the lower values in February and May before implementation. Also in July and August we do not only see the OEE reaching record values for the year at 93,3% and 93% respectively, but the OEE world class performance benchmark being achieved for 2 consecutive months indicating a sign of consistency.

4. Analysis of Results

Maintenance is carried out so that a physical system continues to work properly and fulfils its design intention. The implementation of autonomous maintenance instills a sense of ownership to the operators over the equipment, and maintenance staff ensuring the equipment optimal operation (Kocher, et al, 2012). Outcome of this pillar is a reduced downtime, and improved availability as the system recorded no frequent breakdowns. The reduced downtime after TPM implementation illustrated in figure 3, and an improved availability (figure 4) therefore indicate success in the implementation of autonomous maintenance, with the teamwork of maintenance operators and personnel ensuring that the equipment is always at its best condition.

Although the current implementation quality maintenance pillar is not released, the quality rate is consistently high before and after implementation of the pillars as illustrated by table 1. This can be attributed to the quality practices carried out with the previous implementation that ensure in-process defects were minimally kept. This has been achieved and sustained through the correct and consistent quality practices on the plant level. Kaizen according to (Wakjira, and Ajit, 2012) brings minor improvements continuously in the organisation with all staff being part thereof. The element aims to maximize the equipment effectiveness, by attempting to eliminate all losses through its activities (Mehta, Singh, Gohil, Shah, and Desai, 2003). The minor improvements resulting in the minimization of minor stops, brought a positive impact on the results (figure 5) giving a clear picture of the performance efficiency after implementation. The performance efficiency world class manufacturing target has been achieved for the three months, with the highest value achieved in July at 95,4% and the lowest in August at 95,1%.

TPM elements are known to yield positive results when implemented correctly in manufacturing processes. Kocher, et al (2012) record improvement in the OEE that increased from 75,17% and 85,25% after the implementation of the autonomous maintenance pillar and focused improvement. These authors reported zero customer complaints and zero accidents. Similarly, this case study results show implementation of the foundational practices of TPM leading and managing change, environment, health and safety, teamwork, 5S, visual management, focused improvement and autonomous maintenance as a pillar is a consequence of consistent and an improved OEE having the lowest value at 81,5% after implementation as shown in figure 6 and the highest at 93,3%, as opposed to before implementation (figure 6) with the lowest OEE value at 64,6% and the highest at 89,9%.

5. Conclusion

The literature studied reveals that TPM implementation takes place through a series of steps known as TPM pillars or elements. TPM is a team based approach that thrives on the existence of these pillars [9]. The Japan Institute of Plant Maintenance defines TPM as an 8-pillar house or approach, but this number can change depending on the culture of the company, and organisational needs. TPM elements are very crucial for successful implementation. The elements selected for the implementation, need to address the challenges at the organisation. The TPM elements should be selected based on the organisational goals, in addition to allocating enough time for the actual implementation. Each of the TPM elements constitutes a crucial step to the overall success of the implementation of TPM, as each element addresses certain losses in the manufacturing process or the organisation to perform efficiently in all its departments.

References

Ahuja, I.P.S., and Khamba, J.S, Total productive maintenance: Literature review and directions, International Journal of quality and reliability management, vol. 25, no. 7, pp.709-756, 2008.

Campbell, J. and Reyes-Picknell, J., Uptime: Strategies for Excellence in Maintenance Management, 2nd Edition, Productivity Press, New York, 2006.

Dal, B., Tugwell, P. and Greatbanks, R, Overall equipment effectiveness as a measure of operational improvement–a practical analysis, International journal of operations & production management, vol. 20, no.12, pp.1488-1502, 2000.

de Ron, A.J. and Rooda, J.E, Equipment effectiveness: OEE revisited. IEEE transactions on semiconductor manufacturing, vol.18, no.1, pp.190-196, 2005.

Eti, M.C., Ogaji, S.O.T., and Probert, S.D, Implementing total productive maintenance in Nigerian manufacturing industries. Applied energy, vol. 79, no. 4, pp.385-401, 2004.

Fernández-Muñiz, B., Montes-Peón, J.M. and Vázquez-Ordás, C.J, Relation between occupational safety management and firm performance, Safety science, vol. 47, no.7, pp980-991, 2009.

Iannone, R. and Nenni, M.E, Managing OEE to Optimize Factory Performance Citeseer, 2013.

Kocher, G., Kumar, R., Singh, A. and Dhillon, S.S, An approach for total productive maintenance and factors affecting its implementation in a manufacturing environment, International Journal on Emerging Technologies, vol. 3, no. 1, pp.4-47, 2012.

Kruger, S.J. and Welman, J.C, Research methodology for the business and administrative sciences, 2nd Edition, Oxford University Press, London, 2002.

Levitt, J, Managing factory maintenance, 2nd Edition. Industrial Press, NewYork, USA, 1996.

McKone, K.E., Schroeder, R.G. and Cua, K.O, The impact of total productive maintenance practices on manufacturing performance. Journal of Operations Management, vol. 19, no. 1, pp.39-58, 2001.

Mehta, D.U., Singh, R., Gohil, A.M., Shah, D.B. and Desai, S, Total productive maintenance (TPM) implementation in a machine shop: A case study, Procedia Engineering, 51592-599, 2003.

Moradi, M., Abdollahzadeh R and Vakili, A, Effects of implementing 5S on Total Productive Maintenance: A case in Iran. In Quality and Reliability, IEEE International Conference, pp. 41-45, 2011.

Õrjan L. Measurement of overall equipment effectiveness as a basis for TPM activities, International Journal of Operation and Production Management, vol.18, no.5, pp.495-507, 1998.

Owen C. Total Productive Maintenance, Industry Forum. Business Excellence Through Inspired People, Industry Forum Ltd, Birmingham, United Kingdom, pp. 1-28. 2014.

Sandilands, E. Industrial training, and quality initiatives, Journal of European Industrial Training, vol 18, no.7, pp.1-40, 1994.

Singh, G.B. Keeping the wheels turning: Total Productive Maintenance, Manufacturing Engineer, vol. 85, no.1, pp.32-35, 2006.

Thun, J, Maintaining Preventive Maintenance, and Maintenance Prevention: Analysing the dynamic implications of total productive maintenance. System Dynamics Review, vol.22, no.2, pp163-179, 2006.

Tsarouhas, P, Implementation of total productive maintenance in the food industry: A case study, Journal of quality in maintenance engineering, vol.13, no.1, pp.5-18, 2007.

Vardhan, S., Gupta, P. and Gangwar, V, Industrial Engineering and Operations Management, IEEE International Conference proceedings, Delhi India, 2015.

Visser, K, Practical Components of TPM, Maintenance Management Lecture Note IIB 801, Graduate School of Engineering Management and Technology, University of Pretoria, 2014.

Wakjira, W., and Ajit, P.S.M, Total productive maintenance: A case study in the manufacturing industry, Global Journal of Research in Engineering, no.12, pp1-G, 2012.

Biography

Mthetheleli Kwaso holds a Bachelor of Technology in Chemical Engineering from the University of Johannesburg, and is due to graduate for his MPhil in Engineering Management from the same university. Mr. Kwaso has experience in precious metal refining, FMCG (Fast Moving Consumer Goods) manufacturing, and industrial water treatment. His research interests include renewable sources of energy Biogas to be more specific, business improvement tools, and industrial engineering.