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Methodology of TPM to Increase the Performance & Productivity of Banknote Processing Machines.

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Abstract

Maintenance is an important practice that is used for servicing, repairing and replacing of faulty equipment Maintenance includes but not limited to all actions taken to preserve and retain equipment in serviceable condition, routine work to make sure that the facility works at its designed conditions or capacity, and any activity including testing, measuring, or adjustments. Almost all facilities apply maintenance in their premises to enhance lifetime and productivity. Total productive maintenance (TPM) is a comprehensive path from senior management to those involved in equipment maintenance activities. This paper presents the application of TPM methodology (including 8 pillars) at The Central Bank of Egypt (CBE), to increase the performance and productivity of the banknote processing machines. In addition to discusses autonomous maintenance pillar. Since CBE has a large variety of instruments and equipment, it 'll pave the way for other facilities to follow. The results which uses Overall Equipment Effectiveness (OEE), are compared and concluded.

Keywords: Preventive Maintenance (PM), Total productive maintenance (TPM), Autonomous Maintenance (AM), Central Bank of Egypt (CBE) and Overall Equipment Effectiveness (OEE).

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1. Introduction

The literature has shown that manufacturing organizations worldwide are facing many problems or challenges when performing various operations successfully in this competitive environment. The maintenance aims to keep the system in an operational condition or bring it back to an operational condition after a break down [1-2]. The importance of the maintenance function has increased, due to its role in keeping and improving availability, performance efficiency and product quality. Therefore, equipment care has become very important [3-5]. In principle, maintenance simply consists of keeping equipment in working condition.

The maintenance evolution is formed in four phases. The first phase from 1940 to 1950 include Corrective maintenance. The second phase from 1950 to 1980 works with preventive maintenance. The third phase from 1980 to 2000 contain TPM the fourth one since 2000 with proactive maintenance which seeks to adapt to the strategic. There are three main types of maintenance [6-9].

- Corrective Maintenance: is the maintenance that occurs after the system fails, and it means all actions resulting from failure
- Preventive Maintenance: is the maintenance that is performed before the system failure.
- Predictive Maintenance: is the maintenance strategy that is capable of predicting trend of performance degradation. Also, is the concept of preventive maintenance (PM) has developed into Predictive Maintenance (PdM).

2 Methodology of TPM

As the size and complicity of facilities increased, the need for a more integrated maintenance model emerged. TPM emphasizes corrective and preventative maintenance to maximize the operational efficiency of the equipment [10]. TPM is built on eight pillars [11] as suggested and promoted by the Japan Institute of Plant Maintenance (JIPM). The eight pillars of total productive maintenance focus on proactive and preventive techniques to help improve equipment reliability.

Total Productive Maintenance (TPM) is an inclusive approach from senior management to those involved in equipment maintenance activities [12].TPM can prevent random breakdowns and reduce failures [13].TPM is a systematic approach to understand the equipment's function, the equipment's relationship to product quality, and the likely cause and frequency of failure of the critical equipment components [14].

2.1 BENEFITS AND BARRIERS OF TPM

TPM system requires all employees working in autonomous small groups to work together to eliminate equipment breakdowns [15]. TPM is the best choice to achieve the avoiding wastage in a quickly changing economic environment, producing goods without reducing product quality, reduce cost, produce a low batch quantity at the earliest possible time, goods send to the customers must be non-defective and increasing skills of people (technician, operator, engineer, …etc.) [16]. To further explain, some of the direct benefits of TPM are quality improvement, customer requests fulfillment, and accident reduction. The indirect benefits are increased trust and ownership levels between employees and creates a clean and pleasant work environment [17]. However, TPM application can face some barriers such as lack of commitment at the top management, organization resistance to change, wrong employees' culture, and lack of knowledge about TPM [18], [19].

2.2 TPM MODEL

TPM is consisting of eight pillars are: autonomous maintenance, focused improvement, planned maintenance, quality management, development management, training and education, safety, health and environment [20], [21]. Figure 1 shows the eight pillars of TPM.

TPM application will be significantly increase production performance, employee morale, and job satisfaction [22]. Operators should be involved in maintenance operations to avoid errors in independent maintenance [23]. Independent maintenance will be reduced failures, adjustment losses, improve productivity, product quality and equipment OEE [24].

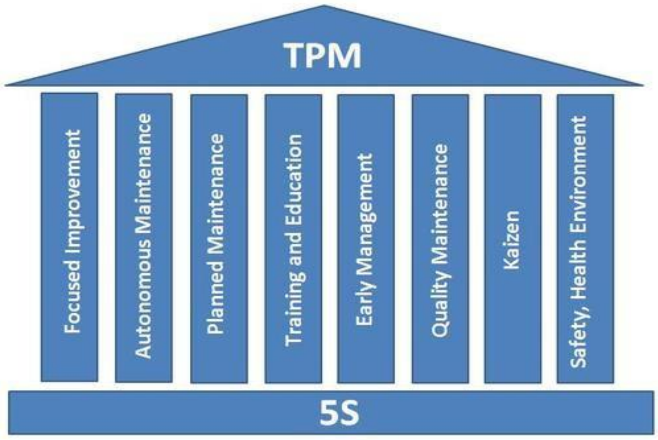

fig. 1 Eight pillars of TPM [15]

2.3 Application of TPM

Many researchers have been experimenting with TPM and conducting experiments to prove their benefit. One study shows the impact of TPM on OEE in chemical processing plant by using single pillar of TPM the third pillar KUBETSU KAIZEN. The OEE of the plant was only 63.35% and after improvement works it rises up to 81.99%. If the improvement work continued, it is possible to achieve standard OEE (95.00%) for this type of chemical [15]. Another study was conducted in the machine shop floor, shows an improvement in OEE from 55.94% to 59.05%. This resulted in the improvement in productivity and quality [10]. A case study from Pakistan applies TPM concept in the business flexible unit equipped with various flexographic printing machines and Overall Equipment Effectiveness has improved from 50% to 53% indicating the improvement in productivity and improvement in quality of product [25]. A different study focuses on the implementation of the proposed TPM model. The study was carried out in the company throughout three months and Improvement of production defects is 72%, Machine's breakdown is 81.25% and product cycle time 26.2% [26]. A study that was conducted in Assela Malt Factory. The study shows the impact of TPM in boiler plant by using single pillar of TPM the first pillar autonomous maintenance. The breakdown time reduced by 46.38% (from 186.39 hours to 99.94 hours per month). OEE has improved from 66.44% to 80.23 % after the application of AM. [27]. Finally, a glazing-line case study, indicated that a glazing line of one company decreased the disruption time from 2502 to 1161 minutes. The OEE increased from 22.12% to 28.61% [28].

2.4 Autonomous Maintenance

The first pillar in the total productive maintenance strategy is Autonomous maintenance. The trained operator in autonomous maintenance strategies has complete information of making tasks such as cleaning, lubricating and inspecting. It requires operators to take responsibility of their equipment and its working area [29]. The two core principles for autonomous maintenance are increasing the operator's knowledge of the equipment they are using and keeping the equipment in the default state: lubricated, cleaned and ready for operation [30], [31], [32]. For Skilled maintenance team need to invest heavily in training and developing. Autonomous maintenance has three a major benefit brings to an organization. The lower labor cost is the biggest benefit. The other benefit of autonomous maintenance to improve the availability of highly skilled maintenance personnel so they can tend to more high needs. Finally, autonomous maintenance increase team co-operation by eliminating the "we/they" mindset [33].

There are 7 steps to be applied to ensure AM. These steps are shown in Figure 2. Firstly, initial cleaning and inspection where the machine is cleaned and checked thoroughly to make sure that it is restored to its original state. Second step, contamination detection and accessibility areas detection to have full access to equipment and control deterioration. Third step, establishment of standards and conditions which allows for regular checks and routine creation. Forth step, guiding the workers through hands on training and on-site sessions to familiarize the workers with the machine and increase their ownership. Fifth step, operators start to conduct general inspection and suggesting modifications to the process to streamline and organize tasks. Sixth step, putting together the autonomous maintenance master plan, which integrate all the results from previous steps. Seventh step, record and collect failures data to continuously analyze and improve the plan, the steps can be repeated if needed. [32], [34], [35], [27].

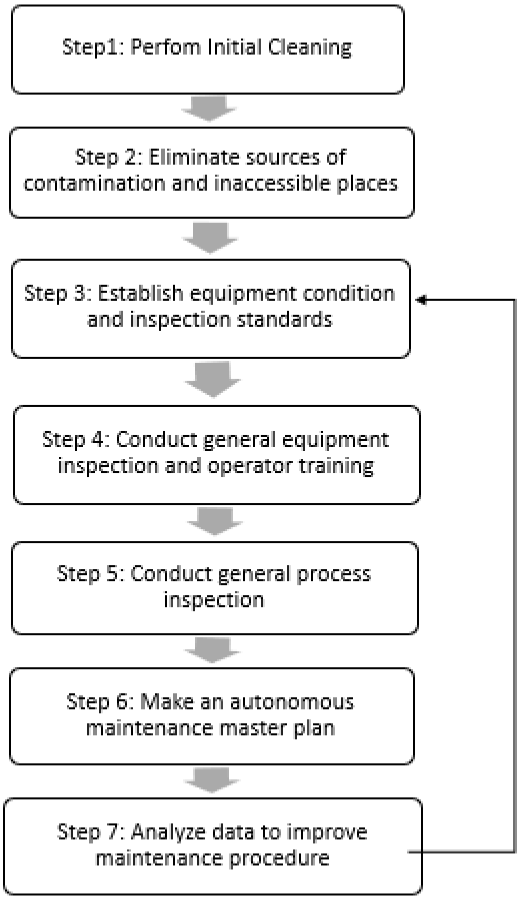

fig. 2 seven steps of autonomous maintenance [34]

2.5 Overall Equipment Effectiveness

OEE (Overall Equipment Effectiveness) is a measure of manufacturing productivity. It defines the percentage of the product's manufacturing time. A 100% OEE means you only manufacture the good parts, as quickly as possible, with no downtime. OEE is a can benchmark for identifying losses, measuring progress, and improving manufacturing equipment productivity. OEE is highly depended on TPM which affects performance, quality, and availability [26]. OEE is governed by the following relation:

OEE=Performance x Availability x Quality

- Availability, includes any events that stop planned production for an appreciable length of time.
- Performance, accounts for anything that causes the manufacturing process to run at less than the maximum possible speed when it is running (including both Slow Cycles and Small Stops).
- Quality, accounts for manufactured parts that do not meet quality standards.

This work indicates the methodology of TPM by

- Collecting data for methodology, productivity and activities
- Analyses the data which calculate OEE to reach the desired objectives and results.

3 PROBLEM DEFINITION

Central Bank of Egypt (CBE) is an important facility and has modern equipment that needs more attention in maintenance. Preventive maintenance alone is not adequate with the importance of its equipment. Moreover, the addition of predictive maintenance is very pricy and hard to implement. Thus, the need for TPM technique arises as a feasible solution for maintenance in such a large facility.

4 AIM OF THE WORK

Application of TPM method to enhance the maintenance processes. This will have a positive impact on productivity and machine life time. To illustrate, TPM facilitates measuring machine breakdowns, availability, performance, and OEE. In addition, TPM allows top management to plan maintenance routine and control employee performance and productivity.

5 IMPLEMENTATION

The study was conducted at a central bank of Egypt, which included operation team, managers, technical team, …etc. Three processes were studied for the BPS M7(Banknote Processing System M7). BPS M7 is a very sophisticated system designed to sort Banknotes. The sorting is not limited to counterfeit banknotes and fit ones, it includes quality sorting to have full control on the cash cycle. This machine is widely used in European banks and north American banks. The BPS M7 uses top notch German technology with its sophisticated mechanical, pneumatic, and electrical systems combined by a very smart software to integrate all these systems in one of a kind engineering equipment. The input is banknote coming directly from the market. Then it is run with speed up to 33 banknote/sec. The banknotes then go to be shredded directly or stacked and packaged to go back to the market. This is a fully automated process that doesn't need any human intervention. the machine has over 100 sensors distributed all over the machine, all connected to different control units connected on a can bus with the main PC. One supervisor, four operators and engineer responsible for each process. The researcher and management are looking for a functional team of five experienced operators of operations consisting of an experienced maintenance technician, a quality engineer and two lead technicians to collaborate in the implementation of the TPM. In this team, the team members were familiar with the maintenance and operation of the selected machines or processes. Autonomous maintenance (AM) was used to improve equipment conditions. The AM implementation is set as an independent variable in this project. The AM execution status used was 'not daily' and 'done daily'. Implementation of AM before and after operations approach, OEE was measured for each machine in the production line.

5.1 Experimental Procedures

Autonomous maintenance plan is applied as the base for this research. TPM is an organized approach to enhance production process through involving everyone such as operators, maintenance technicians, and managers. Three key features of TPM are proactive, preventive and corrective maintenance. Autonomous maintenance leans more towards the preventive and proactive types. Machines with the best conditions are selected to fulfill the AM parameter which requires restoring the condition of equipment in order not to hinder the already existing production plan in CBE. Then TPM would be continually managed in the future daily production.

The research included the following phases:

1. Machines selection
2. Condition evaluation
3. Measurement OEE before implementation of AM
4. Operator training
5. Applying autonomous maintenance
6. Measurement OEE after implementation of AM

According to processing history, three machines are selected to guarantee that they are in a suitable condition for the model. A cross-functional team is formed to start the preparation work before applying TPM. The teams prepared criticality assessment and condition appraisal tables which enabled the researcher with management to formulate basic equipment conditions as showed in table 1. Each team has a role in the process. For example, Operators clean and lubricate the machines, operators and maintenance technicians rank key parts of the process, and the researcher reviews the process and acquaint all the involved team with their roles and responsibilities.

5.2 Impact Assessment Matrix of BPS M7

Our survey on the machine is based on the mentioned parameters in the table 1. choosing the list of parameters as the selected parameters, has more impact on the machine that affects machine productivity. Taking the opinion of three engineers about the listed parameter sensitivity and grade, the list of impact from 1 to 3 as 1 is lower impact and 3 is the high impact.

Table 1. Impact assessment matrix

Equipment description	1-3 ranking of inspection on BPS M7							
	S	A	P	Q	R	M	E	C
Transport	2	3	3	2	3	2	1	2
Singler	3	3	3	3	3	3	1	3
Valves	3	3	3	3	3	3	1	2
Stepper motor	1	3	3	1	2	2	1	3
MDC- [module control board]	1	3	3	3	3	3	2	3
Shredder block	3	2	3	3	3	3	2	3
Photo detector	3	3	3	3	3	3	1	2
Knife	3	3	3	3	3	3	1	2

S=Safety P=Performance 1=No impact

A=Availability M=Maintainability 2=Mid impact

R=Reliability Q=Quality 3=Significant impact

C=Cost E=Environment

5.3 OEE Measurement Before Implementation of AM

Actual machine data is collected for 6 months before starting the AM study to compare OEE before and after model implementation.

5.4 Applying Operators Training

Cooperation of cross function teams was needed to set a schedule of operator training as shown in table 2. In addition, a process is compliantly created with operators and maintenance technicians to guide daily activities such as cleaning, checking, and inspection. Table 3 shows an example of the daily cleaning and inspection checks. By this action we can lead operators to implement concept of autonomous maintenance by make a training schedule, the vision is to make a daily 30 minutes for AM training for the shift operators at the break time to take the operators step by step to achieve and implement the daily meeting targets on their machines. The plan of training should be existing on two weeks by one shift, the is consist of 12 operators and one supervisor. A homogenous process was created by the different teams involved in the process such as the operators, maintenance technicians and Engineers. During this period, the daily cleaning checklist is followed and put into action in accordance with the OEE Measurement after AM. At the start the OEE was calculated based on the previous history data recorded. Next, the OEE was recorded after the TPM had been implemented. Operators recorded any time losses during the work from the reports generated by the machine and then they enter them into Excel forms. After applying all the steps, The OEE data is compared between two phases, prior to AM implementation and after AM Implementation.

Table 2. Cleaning and inspection structure training

NO.	Training Contents	Completed	Competent applicable
1	Clean the CM: a. singler area b. transport section c. sensors d. photo detectors e. air filters f. filter mats g. bundler welding and pressing die clean the NP: h. machine surfaces i. conveyer belts j. sensors k. photo detectors l. air filters m. ventilation grid and filter mat	Yes ☐ No ☐	Yes ☐ No ☐
2	Operate NP a. operating procedures b. perform static printing c. perform dynamic printing d. utilize “Easy Label”	Yes ☐ No ☐	Yes ☐ No ☐
3	Open and close flap doors w/ power off	Yes ☐ No ☐	Yes ☐ No ☐
4	clarify transport disturbances and recover jams: a. clarify transport disturbances and recover jams b. recover jams in sensor and counting area c. recover jams in security area	Yes ☐ No ☐	Yes ☐ No ☐

	d. check shredder display e. continue banknote processing		
5	recover malfunctions with automatic and enhanced automatic loading: a. balance singler content b. empty singler area c. continue banknote processing	Yes □ No □	Yes □ No □
6	recover malfunctions with serial number check: a. with software error b. with too many reject banknotes c. with implausible serial number d. continue banknote processing	Yes □ No □	Yes □ No □

CM=Computer Machine

NP=NotaPack

Table 3. Cleaning check list

Daily Cleaning and inspection check (machine no.783)											
Location and Position	Maintenance work	1/9/2021	2/9/2021	5/9/2021	6/9/2021	7/9/2021	8/9/2021	9/9/2021	12/9/2021	13/9/2021	14/9/2021
Input Module	Clean the Singular Area	√	√	√	√	√	√	√	√	√	√
	Clean the Air Filters	√	√	√	√	√	√	√	√	√	√
Input and Basis Module	NotaMaster Image Sensor	√	√	√	√	√	√	√	√	√	√
	Clean the NotaMaster Automatic	√	√	√	√	√	√	√	√	√	√

	Clean the Filter of the Camera Objectives	√	√	√	√	√	√	√	√	√	√
	Clean the Input Module Sensors	√	√	√	√	√	√	√	√	√	√
	Clean the Basis Module Sensors	√	√	√	√	√	√	√	√	√	√
	Clean the Measurement Window	√	√	√	√	√	√	√	√	√	√
	Clean the transport section	√	√	√	√	√	√	√	√	√	√
	Clean the Photo Detector in the transport section	√	√	√	√	√	√	√	√	√	√
Front of the Machine	Clean the Photo Detector in reject and delivery modules	√	√	√	√	√	√	√	√	√	√
	Clean the Forked Photo detectors on the spiral stacker disks	√	√	√	√	√	√	√	√	√	√
	Clean the Forked Photo detectors on the Shredder	√	√	√	√	√	√	√	√	√	√
	Operator of the Machine Comment	√	√	√	√	√	√	√	√	√	√
	Machine Operator name	1	1	2	1	1	2	2	2	1	2
	Start time	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am	8:00 am
	End time	8:35 am	8:30 am	8:30 am	8:35 am	8:25 am	8:30 am	8:35 am	8:30 am	8:25 am	8:30 am

6 RESULT AND DISCUSSION

This section shows the impact of implementing autonomous maintenance as the first pillar of TPM in CBE Cash Center. Table 4 shows the top 8 reasons that have a direct influence on trouble time. The data is extracted from machine reports and the average trouble time, which is calculated separately. To calculate OEE, first step is to start by collecting data. This data includes the most common failure reasons based on the number of occurrences which effect on the stop timing. In the next step the data is analyzed to define the root causes of failures. Finally, action is taken for every event to decrease stop time and increase the OEE.

The data in table 4 summarizes the top trouble events as shown in machine reports for the period from Jan,2021 to Jun,2021. The total trouble time is a combination of number of occurrences with time which is the main ranking criteria. Table 5 is then generated based on the operators' knowledge and training. This table is very important as it adds another layer to the analysis be looking deeper in every trouble event. It takes the average of three operators' opinion as every one of them gives an opinion based on their level of experience. Based on this analysis, dust is the main reason of trouble events. However, other reasons such as belt slip can be linked to dust. This conclusion confirms that AM is the suitable pillar to be applied to this site.

Table 4. Data from machine

No	Machine: M01000791			Trouble time, minutes		
	Class	Group	No. of events	Average	Maximum	TOTAL
1	General events	Jams	486	00:10	00:86	31:00
2	General events	Shredder	37	01:02	06:41	18:31
3	General events	Stacker/bander	240	00:10	04:54	23:35
4	General events	Bundler	14	00:00	00:04	00:11
5	General events	Sensors	6	00:33	02:41	03:20
6	General events	Photo detectors	9	00:06	00:23	00:59
7	General events	Transport	97	00:02	00:24	03:19
8	General events	Singler	42	00:05	00:53	03:41
	All Events		936	00:05	04:14	85:23

Table 5. Failures name and all reasons that caused failure.

Operators opinion (%)	**Occurrence causes**	**Failure name**			
		O1	O2	O3	AVG
Jam	1-Notes input are not okay.	7	10	9	8.6
	2- Detector sensor need to clean.	25	23	20	22.6
	3 – transport belts are wearing.	5	10	3	6
	4- No signal from position sensor.	3	2	3	2.6
	5-Dust.	60	55	65	60
Shredder	1-dust.	30	28	35	31
	2-Shredder knife need are wearing.	10	13	9	10.6
	3-operation	60	59	56	58.3
Bundler	1-heating element are not clean (Dust)	46	45	41	44
	2- temperature sensor not working	30	35	33	32.6
	3- bundler motor not working	24	20	26	23.33
Sensors	1-Need to clean (Dust)	70	73	72	71.6
	2-calebration	5	3	7	5
	3-not connected (no signal)	25	24	21	23.3

Transport	1- adjustment	17	19	19	18.3
	2- belt slip	45	43	48	45.3
	3-dust	25	28	20	24.3
	4-fault	13	10	13	12
Stacker-bundler	1-position sensor reflector are not clean	35	40	37	37.3
	2-transport chain is not clean	33	30	28	30.3
	3-adjustment	20	15	19	18
	4-fault	12	15	16	14.3
Singler	1-Dust	60	48	53	53.6
	2-adjustment	20	25	23	22.6
	3-fault	20	27	24	23.6

Table 6 compares the OEE of BPS M7 at 2020 before implementing AM and at 2021 after implementing AM average the first 6 months of each year. The average OEE, as figure 3 shows, at 2020and 2021 was respectively 70.5% and 83.2%. The Availability, as figure 4 shows, increased from 88.6% to 92.2%. the Planned production time increased from 1320 Hr. to 1449 Hr. The breakdown time in 2020 was 144 Hr., while it decreased to 108 Hr. in 2021. The Production quality increased from 92% to 98%. The production count per sec. increased from 28.2BN/Sec to 31.1BN/Sec.

Table 6. Results Due to Implementation TPM from 1/2020 to 6/2021

Assessment criteria	Before TPM Implementation	After TPM Implementation
Production quality	92%	98%
Machine breakdowns	144 Hr.	108 Hr.
Availability	83.1%	92.4%
OEE	70.5%	83.2%
Planned production time	1320 Hr.	1449 Hr.
Employee’s satisfaction (%)	80%	87%
Production count /sec.	28.2 BN/Sec	31.1 BN/Sec

BN= Banknote

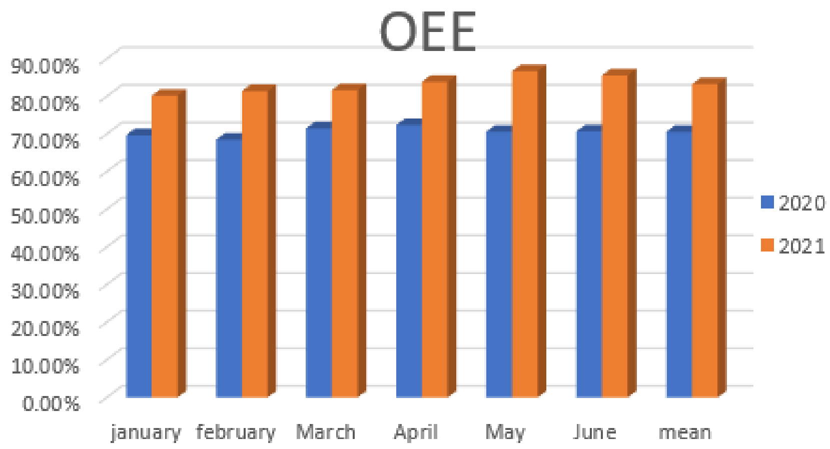

fig. 3 Indicates the improvement of OEE.

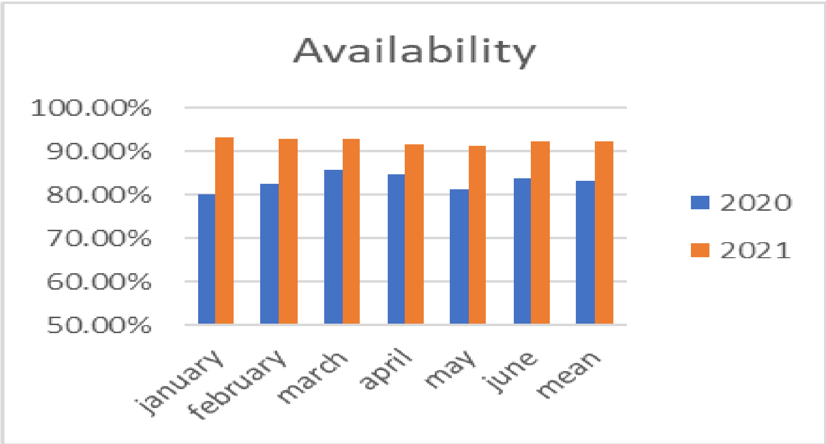

fig. 4 Indicates the improvement.

7 CONCLUSION

This paper discusses a case study of an application of Autonomous Maintenance pillar as part of TPM at the Central bank of Egypt to enhance performance. The present case study is based on collecting data in 2020 & 2021, in real production. The study of applied pillar autonomous maintenance affected the process significantly with OEE increase from 70.5% to 83.2%. The Availability increased from 88.6% to 92.2%. The Planned production time increased from 1320 Hr. to 1449 Hr. In addition, this study has increases awareness of the importance of TPM in CBE facilities. This paves the way for further experiments with other TPM studies. The future plan is to build up on this case study and apply the other pillars of TPM to all CBE facilities.

8 References

[1] I. .. K. P. Ahuj, "A case study of total productive maintenance implementation at precision tubes mills," *Journal of Quality in Maintenance Engineering,* 2009.

[2] W. R. Blischke and D. N. P. Murthy, Case Studies in Reliability and Maintenance, vol. 480, John Wiley & Sons, Inc., 2003.

[3] B. Al-Najjar, "Total quality maintenance: An approach for continuous reduction in costs of quality products.," *Journal of Quality in Maintenance Engineering,* vol. 2, no. 3, pp. 2-20, 1996.

[4] I. Alsyouf, "The role of maintenance in improving companies productivity and profitability.," *International Journal of production economics,* vol. 105, no. 1, pp. 70-78, 2007.

[5] W. G. M. Herman and L. Pintelon, "A framework for maintenance concept development," *International Journal of Production Economics,* vol. 77, no. 3, pp. 299-313, 2002.

[6] J. Moubray, Reliability-Centered Maintenance Second Edition, vol. 1, Industrial Press, 1997.

[7] M. Aladesaye, "Application of predictive maintenance to industry including Cepstrum analysis of a gearbox : a thesis submitted in fulfillment of the requirements for the degree of Doctor of Philosophy," Massey University, 2008.

[8] E. O. d. Souza, M. Z. Fortes and G. B. A. d. Lima, "APPLICATION BASED ON FUZZY LOGIC TO EVALUATE IMPLEMENTATION OF TPM IN INDUSTRIES," *JETIA,* vol. 6, no. v.6 n.22 2020 , pp. 35-41, 2020.

[9] V. M. Z. Wickern, "Challenges and Reliability of Predictive," 2019.

[10] C. K. Kestwal, "Implementation of Total Productive Maintenance," *Tallinn,,* 2017.

[11] P. .. a. J. R. Sangameshwran, "HLL's manufacturing renaissance Indian Management," 2002.

[12] T. Wireman, Total Productive Maintenance Second Edition, Industrial Press Inc., 2004.

[13] C. A. Ortiz, The TPM Playbook: A Step-by-Step Guideline for the Lean Practitioner, New York: Productivity Press, 2016.

[14] S. Nakajima, Introduction to Total Production Maintenance (TPM), Productivity Press, 1988.

[15] S. Islam, "IMPROVEMENT OF OVERALL EQUIPMENT EFFICIENCY (OEE) BY TOTAL PRODUCTIVE MAINTENANCE (TPM),," 2011.

[16] I. A. D. M.R. Rotab Khan, "Development of analytical relation between maintenance, quality and productivity," *Journal of Quality in Maintenance Engineering,* vol. 16, no. 4, pp. 341-353, 2010.

[17] R. B. H. S. Abhishek Jain, "Total productive maintenance (TPM) implementation practice: A literature review and directions," *International Journal of Lean Six Sigma,* vol. 5, no. 3, pp. 293-323 , 2014.

[18] D. V. R. P. D. J. R. V. P. Prasanth S. Poduval, "Barriers in implementation of TPM in industries," *International Journal of Scientific and Technology Research,* vol. 2, no. 5, pp. 28-33, 2013.

[19] R. a. M. G. Griffin, Organizational behaviour: managing people and organizations, South-Western College Pub, 2008.

[20] S. Kumar, R. Bhushan and S. Swaroop, "Study of total productive maintenance & it's implementation approach in steel manufacturing industry: A case study of equipment wise breakdown analysis," *International Research Journal of Engineering and Technology (IRJET),* vol. 04, no. 08, pp. 608-613, Aug 2017.

[21] K. ,. R. a. C. K. McKone, "The impact of total productive maintenance practices on manufacturing performance," *Journal of Operations Management,* 2001.

[22] O. a. L. R. Ohunakin, "Total productive maintenance implementation in a beverage industry: a case

study," *Journal of Engineering and Applied Science,* vol. 7, no. 2, pp. 128-133, 2012.

[23] O. T. R.Almeanazel, "Total productive maintenance review and overall equipment effectiveness measurement," *Jordan Journal of Mechanical and Industrial Engineering (JJMIE),* vol. 4, no. 4, pp. 517-522, 2010.

[24] R. B. a. H. S. A. Jain, "Implementation of Autonomous Maintenance for the Improvement of OEE of machines in SMEs – In Context of Indian Enterprises," in *Proceedings of International Conference on Smart Technologies for Mechanical Engineering (STME-2013)*, Delhi Technological University, Delhi, 2013.

[25] S. Z. S. S. Adeel Shehzad, "Implementation of TPM in a Process Industry: A Case Study from Pakistan," in *16th International Conference on Manufacturing Research (ICMR 2018)At: University of Skövde*, Sweden, 2018.

[26] M. M. A. Sayed, "IMPACT OF TOTAL PRODUCTIVE MAINTENANCE METHODOLOGY ON THE PERFORMANCE," *IJRET,* vol. 04, no. 10, 2015.

[27] W. W. &. A. S. I. Melesse, "Autonomous maintenance: a case study on Assela Malt Factory.," *Bonfring International Journal of Industial Engineering and Management Science,* vol. 4, no. 4, pp. 170-178, 2014.

[28] A. Azizi, "Evaluation Improvement of Production Productivity Performance using Statistical Process Control, Overall Equipment Efficiency, and Autonomous Maintenance," *Procedia Manufacturing 2,* vol. 2, pp. 186-190, 2015.

[29] Y. T. e. T. Osada, Manutenção produtiva total. São Paulo, Portuguese: IMAM, 2000.

[30] S. Raut and N. Raut, "Implementation of TPM to Enhance OEE in A Medium Scale Industry," *International Research Journal of Engineering and Technology (IRJET),* vol. 04, no. 05, pp. 1035-1041, 2017.

[31] J. G. d. S. S. Aglei Duques, "Impact of Autonomous Maintenance on a PIM Production Line," *International Journal for Innovation Education and Research,* vol. 7, no. 12, pp. 385-398, 2019.

[32] k. shirose and s. nakajima, TPM for supervisors, Portland, Or. : Productivity Press, 1992.

[33] A. A. M. MBA, TPM Simplified, Createspace Independent Publishing platform, 2014.

[34] T. Suzuki, TPM in Process Industries, Productivity Press, 1994.

[35] W. T. F. Cloves and C. L. Jandecy, "Applied autonomous maintenance in the improvment of production quality: a case study," *Journal of Engineering and Technology for Industrial Applications,* vol. 2, no. 7, pp. 17-27, 2016.

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