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INCREASING PROFITABILITY OF A MANUFACTURING COMPANY BY USING THE TOTAL PRODUCTIVE MAINTENANCE APPROACH: A REVIEW

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Abstract

In the modern world, a company pays serious attention to productivity and efficiency. Several sectors in the manufacturing world are starting to carry out business transformation, particularly those leading to industry 4.0. This circumstance is driven by efforts to achieve higher productivity and an efficient process, mainly after being economically hit by the Covid-19 pandemic. To maintain efficiency, a manufacturing company should maintain its machine and equipment. Total productive maintenance is a system based on the concept of preventive and predictive maintenance. It is designed to prevent loss resulting from many factors, e.g. production interruption due to failures and adjustments, speed loss due to minor stops and speed reductions, and loss due to defects. Total productive maintenance also provides a tool to measure the level of effectiveness of a machine, i.e. overall equipment effectiveness. This review article focusses on the application of total productive maintenance and overall equipment effectiveness to determine the effectiveness of equipment and eliminate the factors that affect the effectiveness of the equipment.

Keywords: Preventive maintenance, overall equipment effectiveness, production loss

1. INTRODUCTION

In today's modern world, many experts are starting to realize the importance of measurement and existence regarding productivity and efficiency for the manufacturing company [1]. The productivity and efficiency referred to here are the productivity and efficiency of equipment. Many manufacturing companies are currently beginning to perform business transformation, particularly those transforming in the industry's "4.0" era. This is driven by efforts to increase productivity, particularly during the phase of adapting to new habits due to the impact of the COVID-19 pandemic. As of September 2020, the utilities in the manufacturing sector reached 55.3%, i.e. increase by 15–25% from the previous figure of 30–40% at the beginning of the COVID-19 pandemic. The shift towards efficient and effective digitization will link companies with domestic and international markets through an integrated supply chain network. On the other hand, countries with low transformational performance characteristics will experience high costs due to unreliable capacity and efficiency, as well as major barriers to integration and competition in global supply and value chains.

Increasing productivity and efficiency takes a lot of effort. Productivity and efficiency are also closely related to the quality of goods produced by the company. In industry, equipment productivity is an important aspect of the continuity of the manufacturing process. To produce goods of good quality, highly skilled employees with good performance are

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needed. In addition, guaranteed raw materials and supporting materials, equipment or machines that can work optimally, and the right production methods are also a must. For each manufacturing company that uses machines and supporting equipment, speed and accuracy in the process can be achieved when the machine is ready [2]. This is one of the keys to success in the current competitive market.

As the machine life increases and the load of the production process activities also increases, the performance of the machine can decrease. Any outside factor, such as mistakes in running the machine, using the wrong raw materials, or installing the wrong equipment, can also affect how well it works [3]. Production delays are one of the factors that can decrease productivity. If this is ignored, it can deliver a big loss for the manufacturing company. To carry out effective and efficient production, the company must therefore ensure no production interruptions due to machine damage or failure [4]. For this, an appropriate maintenance strategy is needed. Maintenance activities and maintaining facilities or equipment require repairs, adjustments, or replacements to achieve good condition [5].

Total productive maintenance (TPM) is a Japanese system based on the concept of self-prevention or maintenance introduced from the United States in the 1950s and 1960s [6]. The TPM is designed to prevent loss due to downtime, e.g. due to failures and adjustments, loss in speed resulting from minor stops and speed reductions, and loss due to defects caused by defects in process start and decreased yield. The TPM goal is to maximize the efficiency of the entire production system [7]. In addition, the TPM also provides a tool or method for measuring the level of effectiveness of a machine, i.e. the overall equipment effectiveness (OEE). The OEE can be used to evaluate the effectiveness of the equipment used in the production process by using the factors that are in it [8]. The OEE is also used to eliminate factors that affect machine effectiveness [9]. This paper focuses on the application of TPM and OEE in determining the effectiveness of machines and equipment and eliminating the factors that affect their effectiveness.

2. TOTAL PRODUCTIVE MAINTENANCE

For a manufacturing company, predictive and preventive maintenance is one important thing, although it is often forgotten, e.g. seen as a cost center that burdens the company budget. The TPM integrates maintenance and operation functions to achieve a synergy of two independent, yet traditional, activities. The plan is to get rid of organizational boundaries and then change everyone's responsibilities, starting with the field operator and going all the way up to the top executive. Thus, the TPM creates a new work environment for many working groups on the production floor until the management team arrives. A successful TPM is shown by making preventive maintenance more efficient and effective, which then leads to more machines being available and less downtime [10].

The TPM is designed to maximize the effectiveness of the machine by establishing a comprehensive productive maintenance system. It covers the life of the equipment and all areas related to the equipment, e.g. planning, use, care, maintenance, etc. This should coincide with the participation of all employees in the company, from top management to workers on the production floor, to introduce productive maintenance through voluntary motivation or small groups [11]. According to Mwanza and Mbohwa [12], a consistent implementation of TPM can decrease failures and decrease breakdown maintenance below a previous level. The TPM can therefore also support a company's efforts to increase profits and maintain its image, both important factors for maintaining company competitiveness in the current economic turmoil. Shirose [13] noted that a strong foundation and solid pillars are required to implement the TPM in a company. The TPM foundations are the 5S, i.e. (1) *seiri* or concise; (2) *seiton* or neat; (3) *seiso* or rehearsal; (4) *seketsu* or care; and (5) *shitsuke* or diligent. Furthermore, there are eight main pillars of TPM: (1) focused improvement, (2) autonomous maintenance, (3) planned maintenance, (4) training and education, (5) early management, (6) quality maintenance, (7) TPM in administration and (8) safety, health, and environment (Figure 1).

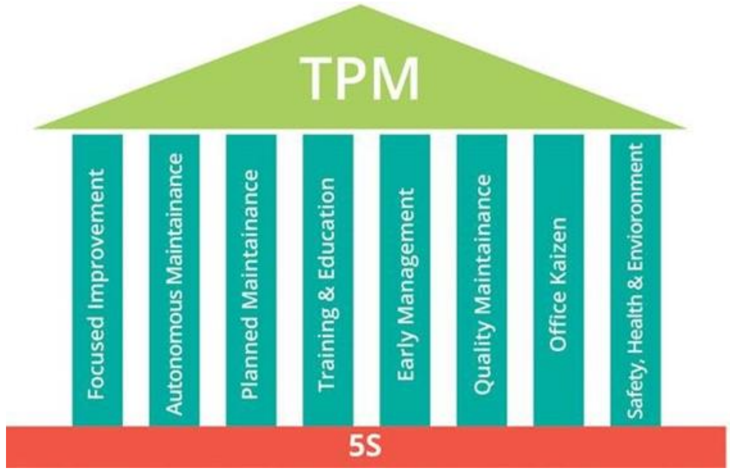

Figure 1. Main pillars for implementation of total productive maintenance [13]

Kigsirisin *et al*. [14] mentioned that TPM's eight-pillar strategy can motivate employees to implement the concept of zero production defects, zero breakdown maintenance, and minimum product loss by maximizing machine effectiveness and enhancing the advanced skills of operators and maintenance personnel. The implementation of daily maintenance consists of cleaning, setting up, and routine inspections, as well as increasing activity and performing minor restorations of equipment. In addition, employees who are responsible for predictive, preventive, and breakdown maintenance should have adequate skills, which can be achieved through prior training and regular practice. This should be implemented on an ongoing basis to maximize machine and equipment efficiency as well as eliminate operator errors and improper repairs. Tsai [10] highlighted good team communication as another key factor for implementing TPM. Amid a machine breakdown, employees in the TPM structure need to communicate with an outside expert maintenance team for technical support. For this, the responsible employees should also receive external training to improve their knowledge and skills. As additional training, team members must continuously update specific technical skills to use new instruments and tools for maintenance. In a man-machine system, the TPM can also be developed to integrate technology with operators.

To implement TPM, information and knowledge about TPM are important factors. Therefore, company executive teams must comprehensively understand this necessity and the workflow of TPM implementation. Only after having a comprehensive understanding of TPM can top management decide to commence TPM implementation in the company. Therefore, the pillars of TPM consist of education and training, early management, office TPM, and work environment health and safety in addition to improving maintenance, scheduled maintenance, and quality maintenance. All TPM models will be directed to achieve targets in TPM, i.e. zero breakdowns, zero defects, and zero adjustments, using productivity, quality, cost, delivery, and safety as the main TPM indicators. For this reason, Mwanza and Mbohwa proposed a model to improve TPM implementation (Figure 2) [12]. The implementation of TPM pillars can eliminate failure rates, improve machine and equipment availability, and decrease all losses. For example, failure rate, preventive maintenance time, repair time, and water loss in chlorinators are decreased so that chlorinators continue to operate with maximum effectiveness [14]. The TPM encourages everyone to get involved and work together, develops the abilities of machine operators, and enhances communication between operators and technicians. In addition, Pinto *et al*. [15] reported increasing operator responsibility for the equipment they operate.

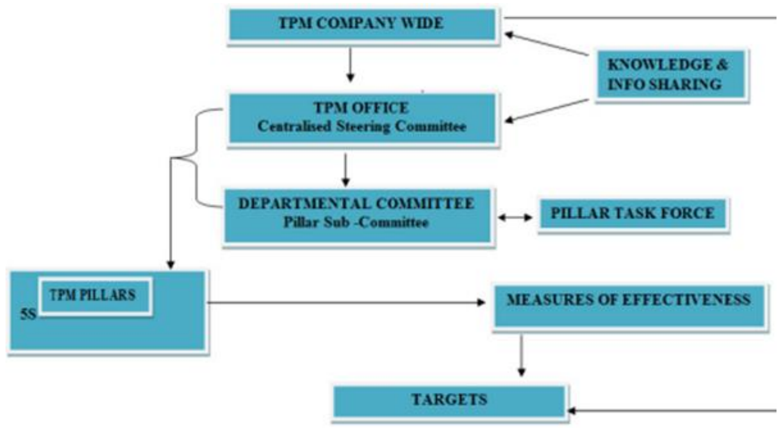

Figure 2. Model for TPM implementation proposed by Mwanza and Mbohwa [12]

3. OVERALL EFFECTIVENESS EQUIPMENT

The determination of overall equipment effectiveness (OEE) is one of many maintenance parameters used in the TPM to measure the level of effectiveness of a machine. Moreover, the OEE is the main performance indicator to measure the effectiveness of TPM implementation. Meanwhile, Dunn [16] highlighted that the OEE can be expressed as a comparison between the actual output of the machine and the maximum output of the machine in its best condition. The OEE quantifies the value of equipment effectiveness and then uses it to eliminate factors that affect machine effectiveness since it can measure the effectiveness of a manufacturing operation [8,9]. The goal of the OEE method is to maximize the resulting output from the available capacity and produce ideal cycle times by reducing downtime, speed, and quality loss as defects [17]. Equation 1 depicts a mathematical model for determining the OEE output. This equation consists of three components that are in line with TPM objectives, i.e. no breakdowns expressed by availability, no small stops or slowdowns expressed by performance, and no product defects expressed by quality [18].

$$\mathrm{OEE} = \mathrm{Availability} \times \mathrm{Performance} \times \mathrm{Quality} \tag{1}$$

In reality, these three components cannot be achieved at 100% [9]. Many world-class companies then set a target of a minimum OEE performance of 85%. For a world-class company, the values of OEE components are 90% for availability, 95% for performance, and 99.9% for quality. This will then result in an overall OEE value of about 85%. However, most manufacturing companies today still achieve an OEE value close to 60%. Nevertheless, the important point is not to focus on the absolute value of the standard but on the improvement effort to increase the future OEE value. Defining the target to achieve a higher OEE value will be a strong driving force for incremental improvements in the manufacturing company. However, the target of the future OEE value should be a realistic one to be achieved. To address this issue, the benchmark value of OEE was outlined by the Japan Institute of Plant Maintenance (JIPM) and is now used worldwide [19]. The first benchmark value is 100% when production is considered perfect. In this case, the company produces without any product defects, works at peak efficiency, and the machine has no downtime. The second benchmark value is 85%. This value is suitable for the company's long-term goals, and the corresponding company is then considered world-class. The next benchmark value is 60%, which is still considered reasonable, but there is still wide room for future improvement. The last OEE benchmark value was 40%, which is a low value and requires significant improvement in the future.

4. FACTORS INFLUENCING THE OVERALL EQUIPMENT EFFECTIVENESS

As previously discussed, the OEE value measures the effectiveness of a machine in the time available for production. The difference between the OEE value of 0 and 100% indicates a technical loss in relation to the available processing time [20]. There are three factors in OEE, i.e. availability, performance, and quality [20]. In their research, Aminnudin *et al*. [21] reported that 75.5% of global companies had implemented the OEE method, while the rest had not. Therefore, a wide window still opens for TPM implementation. Figure 3 shows a mind map to determine the OEE value [22].

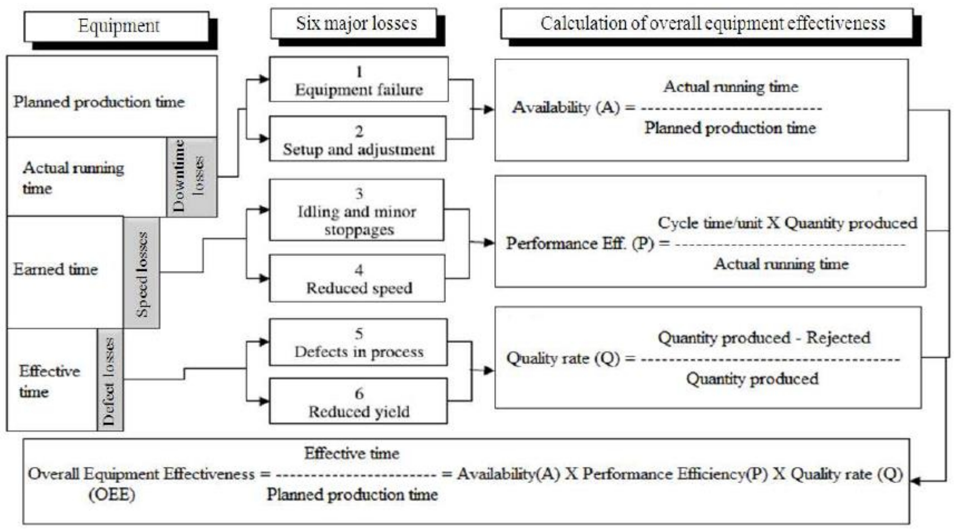

Figure 3. Mind mapping to determine the overall equipment effectiveness [22]

4.1. Availability

Availability is the ratio between the actual operating time, i.e. after reduced by the downtime, and loading time (equation 2). In detail, availability is measured by the total time of equipment operation minus the breakdown time, setup time, and machine adjustment time. In other words, availability is the actual ratio between operating time and the available operating time. Meanwhile, the loading time informs the availability time per day obtained from the planned downtime with the total available time per day or per month. Planned downtime is maintenance that has been scheduled in the initial production plan for machine maintenance, e.g. scheduled repair, predictive and preventive maintenance [23]. Availability in the OEE matrix represents the percentage of scheduled time operations available to operate. Another method to express availability is the percentage of a machine available to produce an item. The availability matrix is a pure measure of uptime designed to exclude the influence of quality, performance and scheduled downtime [24].

$$\text{availability} = \frac{\text{operation time}}{\text{loading time}} = \frac{\text{loading time} - \text{downtime}}{\text{loading time}} \times 100\% \tag{2}$$

4.2. Performance

Performance is defined as the ratio of the actual operating speed of the machine to the ideal speed based on machine capacity (equation 3). As a result, OEE can detect a decrease in production time in an ideal cycle time [23]. Performance represents the running speed of the machine as a percentage of the designed speed. In other words, performance is the actual speed of a production machine compared to the designed machine speed. The performance matrix is a pure speed measure that excludes quality and availability effects [24].

$$\text{performance} = \frac{\text{processed amount} \times \text{ideal cycle time}}{\text{operating time}} \times 100\% \tag{3}$$

4.3. Quality

Quality is defined as the ability to produce products according to a standard that fits the specification as determined by the customer. In other words, quality is the ratio of standardized products to total production and represents the acceptable units produced as a percentage of the total units (equation 4) [25]. Meanwhile, Stamatis [24] stated that the quality matrix used to measure process results is intended to exclude availability and performance effects. Meanwhile, Tatar and Ingaldi [26] conducted research by digitizing several workstations to measure all operational time and downtime as well as the number of products and defects. This strategy increased machine performance and increased operator activity on the production floor. However, a significant decline in product quality was noted amid the performance increases. In this case, the quality decrease does not have a greater impact on the OEE value since the quality decrease in their case could be due to some existing faults that lead to failures and unscheduled downtime.

$$\text{quality} = \frac{\text{processed amount} \times \text{defect amount}}{\text{procesed amount}} \times 100\% \tag{4}$$

Sivakumar and Manivel [20] suggested that a decision to categorize or differentiate quality loss in production implementation must be made. If a quality increase is intended, a decision must be made for the production process and not by adjusting product planning. For the next step, the company must decide the required process for any product that does not achieve the quality standard. When determining quality levels, the company should therefore consider more products that can be traded on the market based on different quality levels.

Cercós *et al*. [27] concluded that a higher difference between operating time and total working time leads to lower availability. In addition, fewer rejected products show higher quality value. The small difference between actual and theoretical speed indicates a higher performance value.Apart from all the possible improvements that occur in all parameters, it is important to know that there must be a balance between production speed and the effect generated. To increase productivity, companies can directly take action in the production process. In this case, however, rejected products may increase. Furthermore, energy consumption may rise, resulting in a greater environmental impact.

A company can determine the quality produced by each machine or by the entire production floor. Hedman *et al*. [28] revealed that if the company does not record any data regarding the actual machine productivity, it is then arduous to calculate the efficiency of performance as the ideal cycle time multiplied by the number of products produced during the actual processing time. But it is possible if the company determines the level of performance on each machine. In addition, if the data regarding quality is not available, then quality cannot be defined as the ratio between the product received and the total amount of production.

4.4. Six Big Losses

Nakajima [29] classified three losses in OEE: downtime loss, speed loss and quality loss. Each loss classification is then divided into two failures. The first type of loss is downtime, which includes equipment or breakdown losses as well as setup and adjustment costs. For speed loss, it can be divided into minor idling and stop loss and decreased speed loss. Quality loss comprises decreased yield, quality defects and rework loss. Since the loss can be broken down into six losses, it is called the six big losses. Each loss has its own role in determining the OEE value. For example, the downtime loss influences the availability factor, the decreased speed loss affects the value of the performance efficiency of the equipment, and the quality loss affects the level of quality in the OEE value. To be more specific, the Japan Institute of Plant Engineering (JIPE) has identified 16 major losses, which are then grouped into six categories (Table 1) [22,29].

Table 1. Major loss in TPM [22,29]

CATEGORY	MAJOR LOSS	EXAMPLE
Planned: scheduled equipment loading time loss	Shutdown loss	Periodic inspection planning for machines
Availability: downtime loss	Failure loss	The functionality of the equipment is down due to the changeover
	Setup and adjustment loss	
	Cutting tool replacement loss	Change of cutting blade
	Startup loss	Production process before stabilization
Performance: speed loss	Minor stops and idling loss	Equipment is temporarily stopped or idle due to sensor actuation or work jam
	Speed loss	The actual operating speed does not reach the planned speed
Quality: defect loss	Scrap and rework loss	Faulty outputs
Manpower: inefficiency loss	Management loss	Waiting for materials, tools, instructions, or tool damage repairs
	Motion loss	Additional moves due to different skills lengthen the design cycle
	Line organization loss	Idle time due to line balancing
	Distribution loss	Man-hour loss due to movement of materials, WIP and product
	Measurement and adjustment loss	Frequent adjustments and measurements to prevent defects from occurring
Resource: consumption loss	Energy loss	Ineffective use of input energy
	Yields loss, consumable loss	Material loss in process Financial loss for repairing or replacing dies, jigs, and tools due to abnormal aging

4.4.1.Downtime Loss

According to Hansen [25], downtime occurs when a machine or piece of equipment does not function properly as designed. In this case, many other things can interfere with the machine or equipment failure, which leads to a decrease in machine processing time. According to Gustavo *et al*. [30], the availability element of OEE measurement relates to the total downtime resulting from unscheduled downtime, machine setup and replacement processes, and other unplanned outages. It can then be concluded that downtime loss is related to availability. There are two classifications of downtime loss, i.e. equipment/breakdown loss, machine setup, and machine adjustment [31].

Equipment/breakdown loss is due to machine and equipment damage, which then requires repair [23]. This loss includes employees' non-productive time due to machine damage and time required for machinery and equipment repair. These activities greatly disrupt production since the disruption of the production process consumes significant time, although the repair time required can be very limited, e.g. in the time range of seconds. Equation 5 can be used to determine the breakdown loss. Meanwhile, equipment failures are categorized as time loss when productivity is decreased and quantity loss when it is due to product defects [29].

$$\text{breakdown loss} = \frac{\text{down time}}{\text{loading time}} \times 100\% \tag{5}$$

Setup and adjustment loss can be due to the required time for machine installation, machine setup, and machine parameter adjustments. This usually occurs before production begins to achieve the desired production specifications. Equation 6 is used to determine setup and adjustment loss [25]. Setup and adjustment losses are the result of downtime and defective products that occur when production of one item ends and a machine is readjusted to meet the requirements for another item to be produced on that machine. In other words, this loss is caused by changes in operating conditions. Examples include the start of production, the start of the next production shift, changes in products produced, and changes in operations that must be made.

$$\text{setup and adjustment loss} = \frac{\text{setup time}}{\text{loading time}} \times 100\% \tag{6}$$

4.4.2.Speed Loss

Hansen [25] stated that speed loss is defined as the difference between the theoretical time per cycle and the actual time to produce a product. On the other hand, performance efficiency measures the difference between the ideal output and the actual output that exists during operation [31]. Thus, it can be concluded that speed loss is closely related to performance. There are two classifications of speed loss. The first one is idling and minor stop loss, while the second is decreased speed loss. Speed loss can occur when the speed needed to produce a product is slower than the output at a predetermined speed. However, speed loss is not related to quality specifications.

Idling and minor stops are caused by equipment stopping due to delays in the supply of raw materials or the absence of operators, although the production process is available. Equation 7 is used to determine the value of idling and minor stops [23]. Idling and minor stops can also occur when production is interrupted by a temporary breakdown or when machines stop temporarily. A temporary stop can occur due to a machine problem, e.g., halting, jamming, and idling [28,29].

$$\text{idling and minor stop} = \frac{\text{non productive time}}{\text{loading time}} \times 100\% \tag{7}$$

Decreased speed loss occurs when the machine is operated below the existing speed standard, which can occur when the operator does not understand the machine setting. Therefore, adequate training for operators is required not only for new machine operators but also for experienced operators to refresh their knowledge. Equation 8 is used to determine the value of decreased speed loss. Decreased speed loss occurs due to decreased production speed below the predetermined speed (equation 8) [23]. This value compares the ideal capacity with the actual workload [28].

$$\text{decreased speed loss} = \frac{\text{operation time} - (\text{ideal cycle time} \times \text{output})}{\text{loading time}} \times 100\% \tag{8}$$

4.4.3.Quality Loss

Defects or quality loss occur when the product does not achieve the required quality specification [29]. Quality loss is classified into two types: rework and quality defect. The rework loss occurs due to product defects during production. Products that do not comply with existing standards should be reworked or categorized as scrap. This rework process requires labor, energy, and resources, e.g., water and electricity. In addition, rejected product that is categorized as scrap is also a loss for the company, although in some cases it can be sold at a much lower price. According to Stephes [23], the rework loss is time wasted producing defective products. In addition, rework loss can occur if the machine is running continuously after the tuning and adjustment process while the product still does not achieve the quality specification. In other words, there are two decisions regarding the rejected product: rework or scrap. Equation 9 can be used to determine the rework loss [23].

$$\text{quality loss} = \frac{(\text{defect during production} + \text{scrap loss}) \times \text{ideal cycle time}}{\text{loading time}} \times 100\% \tag{9}$$

Yield loss occurs when raw materials and products are wasted. There are two reasons for this loss. The first one is loss of raw materials due to product design and manufacturing methods. The second is due to the adjustment of production and machine parameters at the beginning of the production process and when changes in machine or production settings occur [28]. Yield loss, i.e. the time used to produce damaged products when setting up and adjusting, is caused by unused materials or raw material waste. Equation 10 is used to determine the value of yield loss [23].

$$\text{yield loss} = \frac{\text{ideal cycle time} \times \text{number of scrapped products}}{\text{loading time}} \times 100\% \tag{10}$$

5. FUTURE CHALLENGE AND OPPORTUNITY

Efficiency is one of the most important production parameters in a manufacturing company.To maintain the high efficiency value, predictive and preventive maintenance are needed. Due to the increasing life of the machine and the increasing workload, the performance and efficiency may decrease. The TPM method offers a significant advantage over other methods because TPM has numerous advantages when applied in the industry.The implementation of TPM can assist the company in achieving higher profits.

The eight pillars of TPM can be implemented for improvements not only for the equipment and machines but also for employees and the management team. Therefore, more publications based on study cases in a particular company will enrich our understanding of TPM implementation. According to Kigsirisin *et al*. [14], the eight-pillar strategy has the concept of zero defects, zero breakdown, and minimal product loss. It can maximize the effectiveness of the equipment, which is a very important production parameter. The TPM allows all parties in the company to engage and work together to avoid miscommunication within the company [15]. For this reason, the authors suggest consistent implementation of the eight pillars of TPM in the company. The aim is to determine the failures that exist in the company and how to address these failures at their roots. In addition, deeper research related to each pillar of TPM, before and after TPM implementation, including every obstacle for each group of manufacturing industries, e.g., the car industry, textile industry, etc., is an interesting research topic.

6. CONCLUSION

Efficiency is a very important parameter for the company. Total productive maintenance (TPM) is one of many maintenance strategies. The TPM designed to increase the profitability of a manufacturing company integrates all company elements, i.e. from the operator level to the executive level, to work together. Therefore, the authors suggest consistent and gradual implementation of TPM, including determination of overall equipment efficiency as an important parameter. The main aim is to continuously and persistently implement the best available method within the company.

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8. REFERENCES

[1] KEMENPRI, "Transformasi industri 4.0 pacu produktivitas saat pandemi", https://kemenperin.go.id/artikel/22075/Kemenperin:-Transformasi-Industri-4.0-Pacu-Produktivitas-Saat-Pandemi, retrieved on November 18, 2022.

[2] RINAWATI, D.I. and DEWI, N.C., "Analisis penerapan total productive maintenance menggunakan overall equipment effectiveness dan six big losses pada mesin cavitec di PT. Essentra Surabaya", Proceding Senatif: Seminar Nasional Teknologi dan Informatika, pp. 21-26, Universitas Muria Kudus, Kudus, Indonesia, 2014.

[3] SAMAT, H.A., KAMARUDDIN, S., AZID, I.A., "Maintenance performance measurement: A review", Pertanika Journal of Science and Technology, v. 19, n. 2, pp. 188-211, 2011

[4] LAZIM, H. and RAMAYAH, T., "Maintenance strategy in malaysia manufacturing companies: A total productive maintenance (TPM) approach", Business Strategy Series, v. 11, n. 6, pp. 387-396, 2010

[5] ASSAURI, S., Manajemen produksi dan operasi, Jakarta, Lembaga Penerbit Fakultas Ekonomi Universitas Indonesia, 2008.

[6] Díaz-Reza, J.R., García-Alcaraz, J.L., Martínez-Loya, V., Impact analysis of total productive maintenance: Critical success factors and benefits, New York, Springer International Publishing, 2019

[7] SHIROSE, K., TPM for workshop for leaders, Portland, Productivity Press, 1992.

[8] GULATI, R., Maintenance and Reliability Best Practice, New York, Industrial Press Inc., 2009.

[9] VORNE INDUSTRIES, “Overall equipment effectiveness”, https://www.oee.com, retrieved on November 18, 2022.

[10] TSAI, J.W., “Operator empowerment for total productive maintenance”, IFAC Proceedings, v. 29, n. 1, pp. 795-798, June-July 1996.

[11] TSUCIYA, S., Quality maintenance: zero defect through equipment management, Cambridge, Productivity Press, 1992.

[12] MWANZA, B.G. and MBOHWA, C., “Design of a total productive maintenance model for effective implementation: case study of a chemical manufacturing company”, Procedia Manufacturing, v. 4, n. 9, pp. 461-470, 2015.

[13] SHIROSE, K., Total productive maintenance team guide, Portland, Productivity Press Inc., 1995.

[14] KIGSIRISIN, S., PUSSAWIRO, S., NOOHAWM, O., “Approach for total productive maintenance evaluation in water productivity: A case study at Mahasawat water treatment plant”, Procedia Engineering, v. 154, n. 5, pp. 260-267, 2016.

[15] PINTO, G., SILVA, F.J.G., BAPTISTA, A., FERNANDES, N.O., CASAIS, R., CARVALHO, C., “TPM implementation and maintenance strategic plan: A case study”, Procedia Manufacturing, v. 51, pp. 1423-1430, 2020.

[16] DUNN, T., Manufacturing flexible package: Material, machinery, and technique, Amsterdam, Elsevier Inc., 2015.

[17] HUNG, Y.H., LI, L.Y., CHENG, T.C.E., “Uncovering hidden capacity in overall equipment effectiveness management”, International Journal of Production Economics, v. 248, n. 108494, 2022.

[18] ZARREH, A., WAN, H., LEE, Y., SAYGIN, C., JANAHI, R.A., “Cybersecurity concerns for total productive maintenance in smart manufacturing systems”, Procedia Manufacturing, v. 38, pp. 532-539, 2019.

[19] VORNE INDUSTRI, “Introduction to lean manufacturing”, https://www.oee.com/world-class-oee.html, retrieved on November 25, 2022.

[20] SIVAKUMAR, R. and MANIVEL, R., “Analysis on overall equipment effectiveness of pemamek panel processing machine”, Materials Today: Procedings, v. 21, n. 1, pp. 367-370, 2020.

[21] AMINUDDIN, N.A., GARZA-REYES, G.A., KUMAR, V., "An analysis of managerial factors affecting the implementation and use of overall equipment effectiveness", International Journal of Production Research, v. 54, n. 15, pp. 4430 – 4447, 2016.

[22] ESWARAMURTHI, K.G. and MOHANRAM, P.V., “Improvement of manufacturing and evaluation of overall resources effectiveness”, American Journal of Applied Science, v.10, n. 2, pp. 131 – 138, 2013.

[23] STEPHES, M.P., Productivity and reliability-based maintenance management, New Jersey, Pearson Education Inc., 2004.

[24] STAMATIS, D.H., The OEE primer: Understanding overall equipment effectiveness, reliability, and maintainability, New York, Productivity Press, 2010.

[25] HANSEN, R., Overall equipment effectiveness, New York, Industrial Press Inc., 2005.

[26] TATAR, D.K. and INGALDI, M., "Digitization of processes in manufacturing smes – value stream mapping and OEE analysis", Proceding Computer Science, v. 200, pp. 660-668, 2022.

[27] CERCÓS, M.P., CALVO, L.M., DOMINGO, R., "An exploratory on the relationship of overall equipment effectiveness (OEE) variables and CO_2 emissions", Procedia Manufacturing, v. 41, pp. 224-231, 2019.

[28] HEDMAN, R., SUBRAMANIYAN, M., ALMSTRÖM, P., "Analysis of critical factors for automatic measurement of OEE", Procedia CIRP, v. 57, pp. 128-133, 2016.

[29] NAKAJIMA, S., Introduction to TPM (total production maintenance), Cambridge, Productivity Press, 1988.

[30] GUSTAVO, B., NACFE, T., ERIC, C., "Determining production system performance metrics considering machine downtime", IFAC Paper Online, v. 52, n. 13. pp. 1022-1027, 2019.

[31] ALVIRA, D., HELIANTY, Y., PRASSETIYO, H., "Usulan peningkatan overall equipment effectiveness (OEE) pada mesin tapping manual dengan meminimumkan six big losses", Reka Integra Institut Teknologi Nasional, v. 3, n. 3, pp. 240-251, 2015.