

Total Productive Maintenance and the Impact of Each Implemented Pillar in the Overall Equipment Effectiveness

José Carlos Meca Vital¹ and Carlos Roberto Camello Lima²

¹MSc., Production Engineering Graduate Program, Methodist University of Piracicaba, BRAZIL

²Professor, School of Engineering, Mackenzie Presbyterian University, BRAZIL

²Corresponding Author: ccamellolima@gmail.com

ABSTRACT

Total Productive Maintenance (TPM) focuses on maximizing equipment performance, establishing a productive maintenance system that optimizes its life cycle, contributing for the continuous improvement and availability, avoiding early equipment wear, being necessary that the maintenance works on preventing with managerial focus. In this study, the impact of each implemented TPM pillar in the Overall Equipment Effectiveness (OEE) metric was analyzed, evaluating the performance resulting from each implemented pillar. The approach of the research is predicated on the Survey method, based on the intentional sample of the industrial companies in Brazil, which implemented the method. The results evidenced that the Focused Improvement and Planned Maintenance pillars were implemented in most of the respondent companies, being part of different segments, such as metallurgical, food, textile, auto-parts, household appliances, school material, automobile and chemical products. The OEE metric showed the TPM evolution comparing the result at the beginning of the implemented activities and at the end. Other important observation was in the implementation of the pillars, when compared with the suggested literature, a change of priority and sequence occurred. The Autonomous Maintenance pillar was suggested as the second pillar to be implemented. It is implemented only after the Training and Education pillar, which is the fourth suggested pillar. The other pillars were implemented in the original sequence indicated by literature.

Keywords-- Availability, Overall Equipment Effectiveness, Total Productive Maintenance

minor shut-down, production of defective parts, reworking, and losses at the beginning of production [3, 4]. The central structure of TPM method seeks to eliminate or minimize these six main losses related to the production processes [5].

TPM was developed to maximize equipment performance, creating a productive maintenance system that optimizes their life cycle, continually contributing for the improvement and availability, avoiding the early equipment wear through prevention work with management focus [5].

Kanta, Tripathy and Choudhary [6] and Chan *et al.* [7] describe the synergistic relation among all the organization functions, but particularly between the production and maintenance to achieve the continuous improvement of product quality, operational efficiency, productive capacity assurance and safety at work.

According to Singh, Singh and Sharma [8], TPM consists of eight essential pillars: (i) Focused Improvement, (ii) Autonomos Maintenance, (iii) Planned Maintenance, (iv) Education and Training, (v) Early Equipment Management, (vi) Quality Maintenance, (vii) Administration, (viii) Safety, Health, and Environment.

TPM in the organization brings the convergence in the identification and elimination of waste, inefficiency in the production cycle time, production quality faults and improvement in the processes. Thus, TPM is not a specific maintenance policy, it is a culture, a philosophy, it is a new way of thinking for the organization's employees, especially for those in maintenance [9].

The cultural change covers from top management to operators, emphasizing the importance of the TPM method implementation, setting out the policies, goals and the matrix related to the implementation phases. At launch, the commitment, responsibility of each department and employee, is stated to prepare an appropriate environment for the introduction of the method, aiming to eliminate or minimize implementation resistances, natural of human being [10].

The improvement activities are designed to the production progress, focusing on the equipment reliability and assuring the efficient use of the industrial park through the commitment of employees in training, uniting the

I. INTRODUCTION

Due to globalization and the uncertainties that national and international scenes always create, companies need to be efficient in their production processes and, for this to happen, they need the industrial park to be fully available for the production. The TPM – Total Productive Maintenance – method contributes improving the availability of the equipment [1, 2].

TPM mitigates the effect of performance source reduction on industrial processes, such as equipment breakdown, machine set-up adjustments, frequent and

maintenance and production activities [11]. TPM provides a strategy for improving the productivity and quality of the production processes for World Class Manufacturing [12].

The Autonomous Maintenance, one of the most emblematic pillars of TPM, has the mission of integrating operators into basic maintenance activities and providing the polyvalence of operators in their activities [8, 13].

The OEE - Overall Equipment Effectiveness - metric is used to measure the implementation results of each TPM pillar, being composed by the availability, efficiency and quality factors, where these results are multiplied to compound the OEE, representing an indicator that informs the effectiveness of the equipment and how it is being managed [14]. OEE is a monitoring system, necessary to demonstrate equipment availability, if the machine is producing at a proper speed and if the quality is in accordance with the plan [15].

Thus, this article aims to verify the use of the productive system capacity by industrial companies with the implementation of TPM. In the context of full TPM implementation, with its various supporting pillars and having in mind the costs and the long time required to the implementation, it is relevant to know about the effective participation of each pillar on the operational result. This way, the research problem can be formulated by the following question: "What is the individual impact of implementing each TPM pillar on the OEE indicator?"

The central hypothesis of the research related to the presented problem, and that is intended to be confirmed in the course of the work, is that the TPM pillars influence differently the improvements achieved with the implementation. The article evaluates the partial or global implementation of the TPM pillars, accomplished by the industrial companies in Brazil, aiming to analyze the impact of each TPM pillar on the OEE metric, that is, on the overall equipment performance.

II. LITERATURE REVIEW

TPM has adjusted to the companies' needs, contributing to waste elimination activities, reducing the equipment downtime and implementing the scheduled maintenance [16]. For Brodny and Tutak [17], the TPM method provides the basis for the company to achieve the maximum equipment use due to its working philosophy. Ahuja and Khamba [18] point out that the TPM is a method that works on the continuous development, focused on improving the confidence in the use of the equipment, increasing management efficiency through employees' commitment, integrating the maintenance, engineering process and production activities. When used as a strategic method of organization, TPM focuses on contributing to the increase of the equipment availability and life cycle, decreasing the unplanned downtime

production [19]. For Rodrigues and Hatakeyama [16], TPM aims to reorganize the company's structure related to equipment, molds, raw materials, finished products and maintenance planning.

The United States of America introduced the preventive maintenance and Japan was responsible for the evolution of this maintenance way, achieving TPM. The first contact the Japanese organizations had with this technique was in 1950s, after the World War II, when preventive maintenance was incorporated, which evolved to the production maintenance system and, in the 1970s, consolidated the TPM [1]. In Japan, TPM started at Nippon Denso Co. Ltd., automotive components manufacturer that in 1961 introduced the productive maintenance, automation progress, exemplified by "transfer" and, in 1969, the company with the participation of all employees (Total member-participation) received the Award of Excellence in PM (Productive Maintenance) [13]. The beginning of TPM happened with the evolution of the maintenance process. In 1961, industries in Japan began automating production processes, using less workforce. At that time, it seemed that automation would be associated with the Just-in-time (JIT) production and encouraged the maintenance process in the manufacturing and assembly industries to change, giving rise to the Japanese focus, that culminated in TPM ([20].

Sharma, Kumar and Kumar [21] highlight the four generations of the maintenance process evolution in Japan: (i). Corrective Maintenance (BM), (ii). Preventive Maintenance (PM), (iii). Productive Maintenance System (PMS), (iv). Total Productive Maintenance (TPM).

According to Dhillon (2006), maintenance are all the necessary measures to maintain, reestablish the specific conditions of the equipment, programming the actions based on techniques and studies, directing the best way to perform the activities. Viana [19] classifies the maintenance in: (i) unplanned corrective, (ii) planned corrective, (iii) preventive, (iv) predictive, (v) detective and (vi) maintenance engineering.

The unplanned corrective maintenance refers to repairing actions after failure or breakdowns, focusing on restoring the equipment to productive availability, not worrying about the causes and effects that led to the defect [22]. Monteiro, Souza and Rossi [23] complement that the unplanned corrective maintenance results in: (a) high cost of machine downtime, (b) low availability and reliability, (c) low level planning, (d) security and environmental problems. The planned corrective maintenance is performed to eliminate potential failure before it becomes a functional failure. If the detected failure does not bring risk to safety and does not cause quality problem, it is scheduled to be eliminated when it is more convenient for the production process [24].

The preventive maintenance is the performance of inspections, repairs or replacement of the equipment components before the failure occurs. It is performed systematically, based on predefined time intervals, or by opportunity, using certain operational conditions of the equipment or the industrial park to execute the maintenance [25, 26]. Preventive maintenance involves cleaning, lubrication, basic activities to maintain the equipment and plant in proper working conditions, including scheduling and planning components replacement, problematic equipment, aiming to avoid failures [3]. In some conditions, the combination of a Preventive and a Corrective Maintenance politics is found to be the best solution to reach higher availability of the production system [27].

Predictive maintenance is based on monitoring one or more parameters of the equipment, aiming to execute immediately the necessary replacement or repair actions before failure occurs [28]. For Venkatesh [29], the parameters to be monitored in each equipment should be clearly established. Some parameters can be monitored by the equipment operator and, the parameters that require technical knowledge or specific instruments are executed by the maintenance team. According to Levitt [25], the fundamental elements of the predictive maintenance program are: i) performing visual examinations; ii) controlling the temperature; iii) measuring and analyzing vibration; iv) controlling and analyzing lubricants; v) collecting and analyzing the data; vi) controlling pressure; vii) non-destructive testing.

Regarding the monitoring techniques, they are divided into: i) visual, auditory and tactile inspections (subjective), ii) temperature monitoring, iii) thermometry, iv) lubricants monitoring, v) spectrometry, vi) leak detection, vii) vibration analysis, viii) corrosion monitoring, ix) crack detection [28]. Levitt [25] highlights the measures to establish the predictive maintenance program: i) check components to be observed, ii) numerical value of the parameters, iii) measurement procedures of the parameters, iv) set normal, alert and dangerous limits; v) create procedure for registering and tabling measured values; vi) determine in practice and empirically the time intervals between measurements.

The detective maintenance is performed by devices in the investigation, in the equipment, related to hidden failures or not perceptible by the operator. The devices are designed to automatically issue a warning if there is an abnormality with the equipment [19, 28].

The TPM method is important for maintaining the equipment in working conditions and keeping production activities in constant movement [19]. This movement is based on the productive maintenance concept for company in general. The autonomous maintenance is one of the TPM pillars that contributes for the cultural change of the

company in relation to employees and company [11]. As the relationship between employees and company strengthens, productivity increases, eliminating or reducing the influence of losses on availability, efficiency and quality.

Nakajima [1] defined six major losses in equipment, attested by several authors [3, 30-32]: (i) Losses from breakages: also known as breakdown losses, they contribute to the low performance of the equipment by breakage or failure, being classified as chronic or sporadic breakdowns, highlighting two types: (a) sudden breakdown, loss by equipment failure; (b) gradual equipment degeneration, volume loss due to incident of products defect. (ii) Line/adjustment changes (setup): losses are caused due to a stop for changing current configuration to the new item or product configuration, classifying the activities as: (a) turn off the equipment; (b) changing the tools or molds and accessories (setup); (c) changing of raw material when necessary; (d) production adjustment and stabilization of the new item or product, according to the quality inspection; (e) liberation for production by quality. Time should be measured based on the last finished piece or product that was in production, until the first finished piece or product being approved to proceed production. (iii) Losses by idle operation and small stops: during the production process, small stops occur due to production or equipment problems, in many cases, occurring the intervention of the operator or the technical collaborator. When processing the total of small stops, the negative effect on the operational result is felt. Some situations are: (a) stop due to lack of raw material, packaging, liberation of space to store new production; (b) failure (clogging) of the raw material feeding system; (iv) Losses due to falling production speed: losses occur as a result of equipment having to work at lower speed than designed and, in some situations, under inappropriate conditions to the process, such as: equipment methods, molds or peripherals wear. Some of these situations are: operator inefficiency, equipment life. (v) Losses due to defective products/reworking: losses come up from items or products produced with quality defects, occurring rework or disposal. In the production recording, the total production should be accounted, highlighting the approved and rejected production. Some situations are: unfilled, scratched, stained pieces. (vi) Losses from drop in startup performance: losses are related to equipment technical restrictions or operational problems. Examples: temperature variation due to weather changes or inappropriate installations; signal loss or parametrization due to equipment technical problems; scrap; rework.

TPM was based on five pillars at first and, after, three more were added, aiming to promote the planning, organization, monitoring and manufacturing performance control [1]. The first four of the eight pillars are elements

of TPM that aim to maximize the production efficiency, which have direct impact on the manufacturing performance, while the other pillars are elements of support, which improve the manufacturing performance even more [33]. Each pillar plays an important role on solving and improving the equipment availability, where all the pillars integrate and, if used well, they raise the level of organization to “world class” manufacturer, achieving competitive advantages [34].

The Focused Improvement pillar is used to identify the improvements in the production process, measuring the losses in processes to achieve maximum equipment performance [1]. The Autonomous Maintenance pillar includes techniques that liberate operators to maintain the equipment in its best condition, with eventual participation of the maintenance sector, providing the operators basis and support in the maintenance activities at their workstation [35].

Planned Maintenance pillar, as highlighted by Ireland and Dale [36], works so that the organization has the maintenance planning and control, aiming at improvements, observing innovative practices, structuring a database, establishing efficiency indicators of maintenance and results obtained from the equipment, using management methods support. According to Jain et al. [34], the Education and Training pillar, aims to supply the professional shortage, by training professionals, mapping the current situations and projecting what is expected in the future, providing training, education, knowledge and abilities to collaborators.

Early Equipment Management pillar, according to Bonifácio and Bonifácio [37] aims to analyze the purchase of future equipment, investigating ways to reduce the time between purchase and its production start-up, as well as evaluating the impact of new products in the operational performance. The Quality Maintenance focuses on quality activities seeking zero defects, zero accidents in finished pieces and products produced by the organization. For that to occur, it is necessary to work on equipment maintenance concepts, method and molds to produce finished pieces and products in accordance to planned standards [20]. Office TPM pillar is related to administrative areas, purposing to reduce or eliminate losses in the administrative processes, eliminating rework of activities and processes that do not add value, providing improvement in departments related to individual and interdepartmental activities, involving employees and, consequently, improving the business of the organization [38]. The authors complement that the information needs to be quick, clear and precise, therefore, it is necessary to optimize the information flow to the internal and external activities of the organization. Finally, the Safety, Health and Environment pillar seeks zero accident and zero pollution. In this context, the organization will need to

develop trainings and activities to act in the culture and raise employees’ awareness, performing activities to prevent accidents. For this reason, it is important to periodically inspect the equipment and facilities in relation to unsafe activities, and train the evacuation of the workplace in the event of fire [38]. Figure 1 shows the sequence of TPM pillars implementation suggested by several authors [1, 39]. Also, according to these authors, the pillars can be implemented simultaneously, considering their interrelation.



Figure 1. Sequence proposed for TPM pillars’ implementation

Source: Adapted from [1] and [39]

III. METHODOLOGY

The work is predicated on the Survey method and was based on industrial companies chosen by convenience, operating in various sectors in Brazil that use the TPM method. Figure 2 summarizes the steps adopted in the research. The development of each step and the concepts used are presented in detail in the subsections.

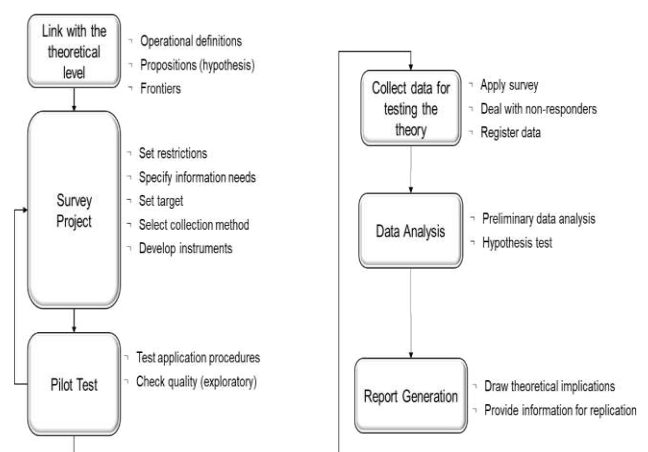


Figure 2. Structuring steps for the survey method

Source: Adapted from [40]

At the initial development of the pilot questionnaire, three companies were chosen, that answered

the questionnaire in order to analyze the objectivity and the coherence of questions. The improvement suggestions contributed to get the questions closer to the companies' routine and meet the research objective.

At the final questionnaire, necessary corrections were made and Google Form tool was used, creating the link <https://goo.gl/forms/MY3kgRByWL9AJRow2>, sent to the research participating companies to answer the questionnaire electronically. The companies invited for the final research were selected by convenience. The contact was made through LinkedIn Software, searching for the responsible for the maintenance area of the company.

The tabulation of data for the questionnaire analysis occurred using the Google Form tool, which later was exported to an Excel spreadsheet for the development of graphics, according to the questionnaire sections. In total, the questionnaire was sent to 11 companies and all of them answered it completely.

IV. RESULTS AND DISCUSSION

Companies with TPM implemented from several segments, such as metallurgical, food, textile, auto-parts, household appliances, school material, automobile, chemical products, were analyzed.

Figure 3 brings the types of maintenance used by the companies. A balanced distribution can be observed among predictive, with 20%, preventive, 22.2%, planned corrective, 24.4% and unplanned corrective maintenance, 24.4%. It is emphasized that the expectation for the last type of maintenance is from a lower rate due to the expected technological evolution and the development of professionals in the implemented process.

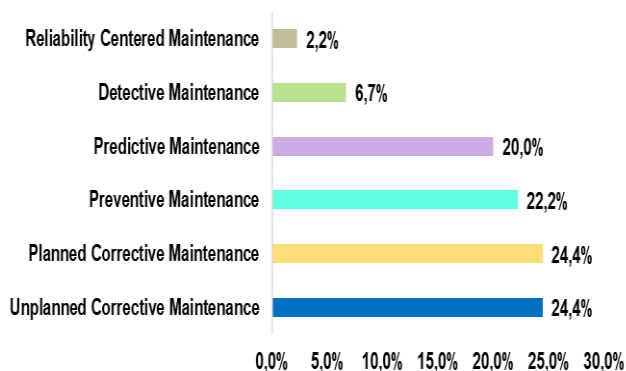


Figure 3: Maintenance types used by the companies

Figure 4 shows the implemented TPM pillars, highlighting the pillars of Focused Improvement, with 17.7%, concentrated on the global improvement of business, and Planned Maintenance, with 17.7%, aiming to plan, execute and control the maintenance program. In

Figure 5, the sequence in which the TPM pillars were implemented is presented.

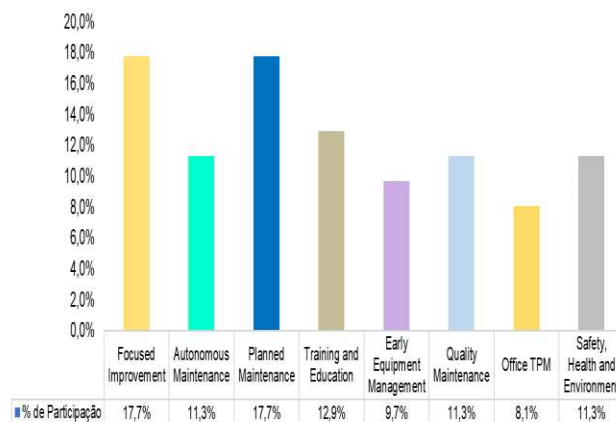


Figure 4: Incidence of implemented TPM pillars

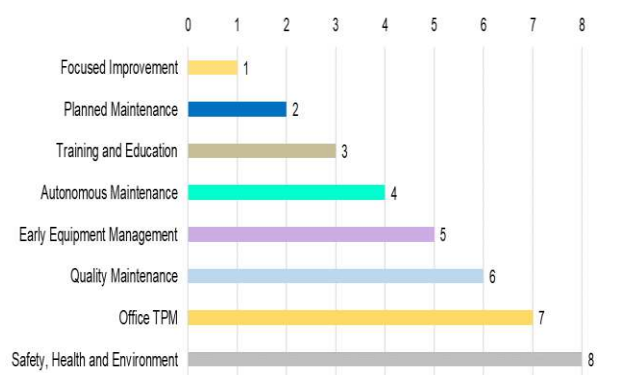


Figure 5: Sequence of TPM pillars' implementation.

Table 1 compares the implementation sequence suggested by the literature and the sequence implemented by the responding companies. To analyze the implementation evolution of the TPM method, the companies were numbered from 1 to 11, to maintain the confidentiality of the respondent companies. The monitoring of the implementation performance evolution of the TPM method was defined by the OEE metric, according to the following statements.

TABLE I: Comparison of the pillars implementation sequence suggested versus accomplished

Position	Suggested Pillars (Fig. 1)	Implemented Pillars (Fig. 4)	Fig. 4 x Fig. 1
1	Focused Improvement	Focused Improvement	Remained
2	Autonomous Maintenance	Planned Maintenance	Anticipated position 3 to 2
3	Planned	Training and	Anticipated

	Maintenance	Education	position 4 to 3
4	Training and Education	Autonomous Maintenance	Postdated position 2 to 4
5	Early Equipment Management	Early Equipment Management	Remained
6	Quality Maintenance	Quality Maintenance	Remained
7	Office TPM	Office TPM	Remained
8	Safety, Health and Environment	Safety, Health and Environment	Remained

Company 1 implemented the pillars of: Focused Improvement; Autonomous Maintenance and Planned Maintenance. When the implementation of Focused Improvement and Autonomous Maintenance pillars began, the global OEE was in 60%, rising to 80% after implementation, with variation of 33.3%. In the implementation of Planned Maintenance pillar, the global OEE was in 70%, rising to 80% after its implementation, with variation of 14.3%. The percentage difference of 80% that was the result of the first implementation and decreases to 70% as starting again the implementation, it happened due to the improvement consolidation period in the implemented activities and keeps oscillating at a certain level and then stabilizes. The Global OEE after stabilization remained at 80% and, comparing to the initial OEE of 60%, it achieved a global improvement of 33.3%.

Company 7 implemented the pillars of: Focused Improvement; Autonomous Maintenance; Planned Maintenance; Training and Education; Safety, Health and Environment. When the implementation of Focused Improvement, Autonomous Maintenance, Planned Maintenance, Training and Education, Safety, Health and Environment pillars began, the global OEE was 80%, rising to 90%, with a variation of 12.5%. Comparing company 7 and company 1, based on the 3 similar pillars

(Focused Improvement; Autonomous Maintenance and Planned Maintenance, adding 2 of the pillars - Training and Education; Safety, Health and Environment), the percentage variation was lower due to the initial basis, which was in 80%. That means the TPM methodology culture was already used in the daily activities. The Global OEE remained at 90% and, comparing to the initial OEE of 80%, it achieved an improvement of 12.5%.

Company 8 implemented all the eight pillars: Focused Improvement; Autonomous Maintenance; Planned Maintenance; Training and Education; Early Equipment Management; Quality Maintenance; Office TPM, Safety, Health and Environment. Implementing the Focused Improvement pillar, the global OEE was 50%, rising to 70%, with the variation of 40%. With the implementation of Planned Maintenance pillar, the global OEE was 50%, rising to 60%, with a variation of 20%. The same phenomenon in Company 1 is observed, the difficult in keeping the OEE metric constant, due to the oscillation on daily activities and the persistence in the problem solutions. In the implementation of Quality Maintenance and Safety, Health and Environment pillars the global OEE was 70%, rising to 80%, with a variation of 14.3%. Quality Maintenance pillar focuses on establishing a zero-defect program. Safety, Health and Environment pillar focuses on establishing a health, safety and environment system, seeking zero accident, zero pollution and better working condition. The Global OEE remained in 70% and, comparing to the initial OEE of 60% on average, it achieved an improvement of 16.7%.

Table 2 shows the monitoring of the TPM pillars and the comportment of the OEE metric, evaluating the performance of the implemented pillars, with the columns before, after and the % variation of OEE. Table 3 shows the big losses and which OEE element contributed for its improvement.

TABLE II. Monitoring of TPM pillar implementation and resulting OEE metric variation

Name of the Respondent Company	Respondent Company - Implemented TPM or not	Focused Improvement			Autonomous Maintenance			Planned Maintenance			Training and Education			Early Equipment Management			Quality Maintenance			Office TPM			Safety, Health and Environment			Total				
		Before	After	% Variation	Before	After	% Variation	Before	After	% Variation	Before	After	% Variation	Before	After	% Variation	Before	After	% Variation	Before	After	% Variation	Before	After	% Variation	Before	After	% Variation		
1	Sim	60%	80%	33,3%	60%	80%	0,0%	70%	80%	14,3%																		60%	80%	33,3%
2	Sim	60%	70%	16,7%	60%	70%	0,0%	60%	70%	16,7%						60%	70%	16,7%				60%	70%	16,7%	60%	70%	16,7%	60%	70%	16,7%
3	Sim	50%	80%	60,0%	50%	80%	0,0%	50%	80%	60,0%						50%	80%	60,0%				50%	80%	60,0%	50%	80%	60,0%	50%	80%	60,0%
4	Sim	50%	80%	60,0%				50%	80%	60,0%			50%	80%	0,6													50%	80%	60,0%
5	Sim	10%	10%	0,0%	10%	10%	0,0%	10%	10%	0,0%						10%	10%	0,0%				10%	10%	0,0%	10%	10%	0,0%	10%	10%	0,0%
6	Sim																											10%	10%	0,0%
7	Sim	80%	90%	12,5%	80%	90%	0,0%	80%	90%	12,5%												80%	90%	0,0%	80%	90%	12,5%	80%	90%	12,5%
8	Sim	50%	70%	40,0%				50%	60%	20,0%						70%	80%	14,3%				70%	80%	0,0%	60%	70%	16,7%	60%	70%	16,7%
9	Sim	20%	50%	150,0%				10%	40%	300,0%						10%	30%	200,0%				30%	40%	33,3%	20%	50%	150,0%	20%	50%	150,0%
10	Sim	30%	60%	100,0%	30%	50%	-16,7%	40%	60%	50,0%						30%	50%	66,7%				30%	70%	133,3%	30%	60%	100,0%	30%	60%	100,0%
11	Sim	80%	90%	12,5%				80%	90%	12,5%																		80%	90%	12,5%

TABLE III. Big losses and the OEE element contributing to its improvement

Large Losses	Focused Improvement		Autonomous Maintenance		Planned Maintenance		Training and Education		Early Equipment Management		Quality Maintenance		Office TPM		Safety, Health and Environment		All Pillars Total	
	Large Losses	%Participation	Large Losses	%Participation	Large Losses	%Participation	Large Losses	%Participation	Large Losses	%Participation	Large Losses	%Participation	Large Losses	%Participation	Large Losses	%Participation	Large Losses	%Participation
Equipment breakdown	9	12,0%	5	9,6%	11	14,3%	5	8,5%	2	10,0%	5	10,2%	0	0,0%	3	6,7%	40	10,5%
Downtime	8	10,7%	6	11,5%	8	10,4%	5	8,5%	3	15,0%	4	8,2%	0	0,0%	3	6,7%	37	9,7%
MTBF (Mean time between failures)	6	8,0%	4	7,7%	7	9,1%	5	8,5%	0	0,0%	4	8,2%	0	0,0%	3	6,7%	29	7,6%
MTTR (Mean time to repair)	9	12,0%	6	11,5%	10	13,0%	6	10,2%	1	5,0%	4	8,2%	0	0,0%	4	8,9%	40	10,5%
Single-Minute Exchange of Die (smed)	6	8,0%	2	3,8%	5	6,5%	3	5,1%	1	5,0%	3	6,1%	0	0,0%	3	6,7%	23	6,1%
Line change or adjustment	6	8,0%	4	7,7%	5	6,5%	5	8,5%	3	15,0%	6	12,2%	0	0,0%	4	8,9%	33	8,7%
Idle operation or small stops	4	5,3%	2	3,8%	5	6,5%	2	3,4%	0	0,0%	3	6,1%	0	0,0%	1	2,2%	17	4,5%
Speed drop	3	4,0%	3	5,8%	5	6,5%	2	3,4%	2	10,0%	3	6,1%	0	0,0%	2	4,4%	20	5,3%
Reduction of the number of accidents	8	10,7%	6	11,5%	6	7,8%	7	11,9%	1	5,0%	4	8,2%	1	33,3%	7	15,6%	40	10,5%
Reduction of the number of incidents	6	8,0%	5	9,6%	6	7,8%	7	11,9%	1	5,0%	4	8,2%	1	33,3%	7	15,6%	37	9,7%
Defective production or rework	5	6,7%	4	7,7%	5	6,5%	6	10,2%	4	20,0%	5	10,2%	1	33,3%	3	6,7%	33	8,7%
Drop in startup performance	5	6,7%	5	9,6%	4	5,2%	6	10,2%	2	10,0%	4	8,2%	0	0,0%	5	11,1%	31	8,2%

OEE Elements

																			Average
Availability	58,7%	51,9%	59,7%	49,2%	50,0%	53,1%	0,0%	44,4%	45,9%										
Efficiency	28,0%	30,8%	28,6%	30,5%	20,0%	28,6%	66,7%	37,8%	33,9%										
Quality	13,3%	17,3%	11,7%	20,3%	30,0%	18,4%	33,3%	17,8%	20,3%										

Figure 6 shows the average distribution of the big losses with impact in the OEE elements, as follows: Availability, with average index of 45,9%, and in all of them, the larger contribution is on the reduction of equipment breakdown, average index of 10,5%, Downtime, average index of 10,5%, and MTTR (mean time to repair) 9,7%; Efficiency, large losses contributed to 33,9%, leading to a reduction of the numbers of accidents, average index of 10,5%; Quality, large losses contributed to 20,3%, in a balanced way, as: defective production or

rework, average index of 8,7% and drop in the startup performance, average index of 8,2%.

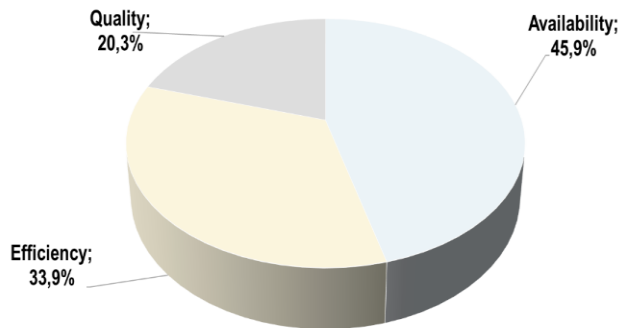


Figure 6: Average distribution of the big losses with impact in the OEE elements.

V. CONCLUSION

The main question of this research, proposed in the initial hypothesis, was proved: TPM pillars influence differently the improvements obtained with the implementation, the results were monitored and evidenced by the OEE metric.

Based on the results and discussions presented, the following conclusions can be reached:

- Regarding the sequence of the implanted TPM pillars, compared to what the literature suggests, there was a reversal of position especially in the implantation of the Planned Maintenance and Education and Training pillars before the Autonomous Maintenance pillar, usually suggested and implanted shortly after or concurrently with the pillar Focused Improvement.
- The results evidence that the Focused Improvement and Planned Maintenance pillars were implemented for most of the respondent companies, working on different segments, such as: metallurgical, food, textile, auto-parts, household appliances, school material, automobile, chemical products.
- In the analysis of the evolution results of the TPM pillars, it was verified the importance of the Specific Improvement and Planned Maintenance pillars, which, after its implementation, led to an increase in the OEE metric, with improvements between 12.5 and 33.3%, showing the performance improvement that these pillars provide.

REFERENCES

[1] Nakajima, S. (1989). *Introdução ao TPM - Total Productive Maintenance*. São Paulo: IMC, 1989. pp. 106.

[2] Shinde, D.D & Prasad, R. (2018). Application of AHP for ranking of total productive maintenance pillars. *Wireless Personal Communications*, 100(2), 449–462.

[3] Kardec, A. & Nascif, J. (2012). *Manutenção função estratégica*. (4th ed.). São Cristóvão - RJ: Quality Mark.

[4] Gupta, P. & Vardhan, S. (2016). Optimizing OEE, productivity and production cost for improving sales volume in an automobile industry through tpm: a case study. *International Journal of Production Research*, 54(10), 2976–2988.

[5] Mwanza, B.G. & Mbohwa, C. (2015). Design of a total productive maintenance model for effective implementation: Case study of a chemical manufacturing company. *Procedia Manufacturing*, 4(1), 461-470.

[6] Kanta, N.K., Tripathy, J.K., & Choudhary, B.K. (2005). Implementing the office Total Productive Maintenance (“Office TPM”) program: A library case study. *Library Review*, 54(7), 415–424.

[7] Chan, F.T.S. et al. (2005). Implementation of total productive maintenance: A case study. *International Journal of Production Economics*, 95(1), 71-94.

[8] Singh, J., Singh, H., & Sharma, V. (2018). Success of TPM concept in a manufacturing unit – A case study. *International Journal of Productivity and Performance Management*, 67(3), 536–549.

[9] Ahuja, I.S. (2006). *Improved organizational behavior through strategic*. Proceedings of IMECE2006 ASME International Mechanical Engineering Congress and Exposition, Chicago, Illinois, USA.

[10] Jonsson, P. (1997). The status of maintenance management in swedish manufacturing firms. *Journal of Quality in Maintenance Engineering*, 3(4), 233–258.

[11] Kumar, J., Soni, V.K., & Agnihotri, G. (2014). Impact of TPM implementation on indian manufacturing industry. *International Journal of Productivity and Performance Management*, 63(1), 44–56.

[12] Mitchell, E.D., Robson, A., & Prabhu, V.B. (2002). The impact of maintenance practices on operational and business performance. *Managerial Auditing Journal*, 17(5), 234–240.

[13] Habidin, N.F. et al. (2018). Total productive maintenance, kaizen event, and performance. *International Journal of Quality & Reliability Management*, 35(9), 1853–1867.

[14] Nunes, I.L. & Sellitto, M.A. (2016). Implantação de técnicas de manutenção autônoma em uma célula de manufatura de um fabricante de máquinas agrícolas. *Revista Produção Online*, 16(2), 606–632.

[15] Shaaban, M.S. & Awni, A.H. (2014). Critical success factors for total productive manufacturing (TPM) deployment at egyptian fmcg companies. *Journal of Manufacturing Technology Management*, 25(3), 393–414.

[16] Rodrigues, M. & Hatakeyama, K. (2006). Analysis of the fall of TPM in companies. *Journal of Materials*

Processing Technology, 179(1–3), 276–279.

[17] Brodny, J. & Tutak, M. (2017). Application of elements of TPM strategy for operation analysis of mining machine. IOP Conference Series: *Earth and Environmental Science*, 95(4). DOI:10.1088/1755-1315/95/4/042019.

[18] Ahuja, I.P.S. & Khamba, J.S. (2008). Assessment of contributions of successful tpm initiatives towards competitive manufacturing. *Journal of Quality in Maintenance Engineering*, 14(4), 356–374.

[19] Viana, H.R.G. (2002) *Planejamento e controle da manutenção*. (6th ed.). São Cristovão - RJ, Quality Mark.

[20] Werkema, M.C.C. (1995). *As ferramentas da qualidade no gerenciamento de processos*. [s.l.] Universidade Federal de Minas Gerais - biblioteca central - DFDA / intercâmbio.

[21] Sharma, R.K., Kumar, D., & Kumar, P. (2006). Manufacturing excellence through TPM implementation: a practical analysis. *Industrial Management and Data Systems*, 106(2), 256–280.

[22] Lima, G.B.A., Gomes, N.D., & Mendonça, R.R.S. (2002). Manutenção produtiva total: Proposta de um instrumento de avaliação objetivando verificar o grau de adequação aos pilares da TPM. In *XXII Encontro Nacional de Engenharia de Produção*.

[23] Monteiro, C.I., Souza, L.R., & Rossi, P.H.L. (2010). *Manutenção corretiva. manutenção corretiva: manutenção e lubrificação de equipamentos*. Universidade Estadual Paulista, Bauru, SP, Brazil.

[24] Bloom, N. (2006). *Reliability centered maintenance (RCM): Implementation made simple*. [s.l.] London: McGraw-Hill.

[25] Levitt, J. (2009) *The handbook of maintenance management*. (2nd ed.). New York: Industrial Press.

[26] Shin, J., Morrison, J.R., & Kalir, A. (2016). optimization of preventive maintenance plans in G/G/m queueing networks and numerical study with models based on semiconductor wafer fabs. *International Journal of Industrial Engineering*, 23(5), 302-317.

[27] Kim, W., Yang, J., & Ahn, S. (2009). Determining the periodic maintenance interval for guaranteeing the availability of a system with a linearly increasing hazard rate. *International Journal of Industrial Engineering*, 16(2), 126-134.

[28] Branco Filho, G. (2008). *A organização, o planejamento e o controle da manutenção*. (1st ed.). Rio de Janeiro: [s.n.].

[29] Venkatesh, J. (2007). An introduction to total productive maintenance (TPM). http://www.plant-maintenance.com/articles/tpm_intro.shtml. *The Plant Maintenance Resource Center*, pp. 1–18.

[30] Shirose, K. (1996). *New implementation program in fabrication and assembly industries*. Tokio: JIPM.

[31] Wireman, T. (1992). *Total productive maintenance: An american approach*. (1st. ed.). New York: Industrial Press.

[32] Salvendy, G. (2001) *Handbook of industrial engineering*. (3rd ed.). New York, John Wiley.

[33] Suzuki, T. (1994). *TPM in process industries*. New York: CRC Press.

[34] Jain, A. et al. (2012). Implementation of TPM for enhancing oee of small scale industry. *International Journal of IT, Engineering and Applied Sciences Research*, 1(1), 125-136.

[35] Gomes, M.C., Lima, C.R.C., & Silva, I.B. (2012). Implantação da lubrificação. autônoma como ferramenta essencial do TPM: Uma abordagem prática. In *Proceedings of the XXXII Encontro Nacional de Engenharia de Produção - ENEGEP, Bento Gonçalves, RS, BR*.

[36] Ireland, F. & Dale, B.G. (2001). A study of total productive maintenance implementation. *Journal of Quality in Maintenance Engineering*, 7(3), 183–191.

[37] Bonifácio, M.A. & Bonifácio, M.R.C. (2013). Pilar de controle inicial do TPM como ferramenta de maximização de projetos – proposta de modelo de implantação. *Iberoamerican Journal of Industrial Engineering*, 3(5), 198–215.

[38] Wickramasinghe, G.L.D. & Perera, A. (2016). Effect of total productive maintenance practices on manufacturing performance investigation of textile and apparel manufacturing firms. *Journal of Manufacturing Technology Management*, 27(5), 713–729.

[39] Suzuki, T. (1992). *New directions for TPM*. Cambridge, USA: Productivity Press.

[40] Forza, C. (2002). Survey research in operations management: A process-based perspective. *International Journal of Operations and Production Management*, 22(2), 152–194.