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The value of TPM for Portuguese companies

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Abstract

Purpose – The purpose of this paper is to assess the impact of a maintenance philosophy, Total Productive Maintenance (TPM), on the operational performance of the Portuguese industry, identifying how it enables the systematic reduction of waste in maintenance.

Design/methodology/approach – A structured questionnaire was constructed and sent to 472 Portuguese enterprises, having obtained a sample constituted of 84 valid answers. With a five-point Likert scale, it was possible to assess the impact of the TPM on five operational performance dimensions, being them: quality, flexibility, productivity, safety and costs.

Findings – It was found that the planned maintenance, together with education and training are the practices with the highest degree of implementation in the Portuguese industry, exceeding 70% for both. The productivity is the dimension with a higher degree of impact from the implementation of TPM and costs the dimension that suffered a lesser impact.

Practical implications – This paper shows and analyses the current state of TPM implementation in the Portuguese industry and it will be useful for maintenance professionals, researchers and others concerned with maintenance, in order to understand the effects of TPM implementation on the operational performance of the Portuguese industries.

Originality/value – The findings from this paper will be valuable for professionals who desire and are looking forward to implement an effective maintenance approach in the maintenance management system, in order to achieve the excellence in maintenance.

Keywords Total productive maintenance, Quality system, Quality maintenance, Industrial maintenance, Portuguese industry

Paper type Research paper

1. Introduction

In the highly dynamic and constantly evolving technological environment that characterizes current times, the increase in global competitiveness has led companies to take a determined look at their global performance, in order to achieve competitive advantage (Ahuja and Kumar, 2009). In a particular way, the manufacturing industries have undergone profound changes in the past decades, starting from management approaches and manufacturing technologies, as well as increased pressure from customers and suppliers. These challenges, in a global way, are forcing companies to seek continuous improvement of their processes and products, through the implementation of strategic and proactive tools, so that they can be competitive in the environments in which they operate (Ahuja and Khamba, 2008). For a long time, industrial maintenance was placed in the background, considered a necessary evil for companies, many of which used a reactive strategy for it, replacing machines only when they stopped working (Swanson, 2001). However, as a result of the exponential increase in terms of investment required for the acquisition of equipment, it became of vital importance to align

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the maintenance activities, resources and tasks with the corporate strategy (Gomes *et al.*, 2020), which put the maintenance department of today under huge pressure to slash costs and show outcome (Phogat and Gupta, 2019), so the organizations started to implement effective and efficient maintenance strategies, in order to achieve an improvement in the performance of the productive systems (Attri *et al.*, 2013). In this way, companies have been replacing this type of reactive approach with proactive and aggressive maintenance strategies, such as TPM, which combine preventive and predictive maintenance activities, in order to avoid the occurrence of equipment failures, simultaneously seeking to improve the function and design of equipment (Swanson, 2001). TPM emerges as a methodology for improving productivity and quality, which consists of an innovative approach to maintenance, aimed at optimizing the efficiency of equipment, seeking to eliminate faults/failures, in order to enable an increase in the cycle of maintenance. Machines life, in the ideal operating conditions of the equipment (Singh *et al.*, 2013) needs maintenance.

The main objective of the present investigation is to evaluate the degree of implementation of TPM in the Portuguese industry, as well as to analyze the impact resulting from the implementation of these two sets of practices in the operational performance of organizations. For these purposes, a questionnaire was built, addressed to 472 organizations, having obtained 97 responses, which is equivalent to a response rate of approximately 21%.

2. Literature review

It was carried out a systematic analysis of the literature, in order to identify the relationship between TPM and maintenance, aiming at the study of the major contributions of the TPM practices implementation on the operational performance of organizations toward better product quality (Costa *et al.*, 2019; Marques *et al.*, 2018; Sá *et al.*, 2019, 2020; Santos *et al.*, 2019a; Bravi *et al.*, 2019) protecting the environment (Carvalho *et al.*, 2020; Araújo *et al.*, 2019; Barbosa *et al.*, 2018; Santos *et al.*, 2014; Bravi *et al.*, 2020; Jiménez-Delgado *et al.*, 2020; Talapatra *et al.*, 2019) and consequently, achieving greater customer satisfaction (Bravi *et al.*, 2017), creating value (Bravi *et al.*, 2018; Santos *et al.*, 2019b; Felix *et al.*, 2019a; Zgodavova *et al.*, 2020; Marinho *et al.*, 2020) and valuing new business (Doiro *et al.*, 2017, 2019; Santos *et al.*, 2018b; Félix *et al.*, 2019b; Rodrigues *et al.*, 2019) where new ideas are welcome (Santos *et al.*, 2018a, 2019c; Azevedo *et al.*, 2019), for rapid improvement (Rodrigues *et al.*, 2020; Vieira *et al.*, 2019; Ribeiro *et al.*, 2019; Murmura *et al.*, 2021).

Santos *et al.* (2011) developed a system called Plug and Lean, based on TPM, with the objective of providing a reliable diagnosis of the current state of the equipment, focusing on the display of graphical information regarding the performance restrictions of the equipment toward improvement activities, allowing the collection of data from production equipment with high precision and with less effort. The first case study took place at a company that manufactures natural wood cladding solutions where the initial variability in line availability and performance has been eliminated, with an increase in Overall Equipment Effectiveness (OEE) from 53.5% to 74.7%. The second case study took place in a large bread producer in 2009, with an improvement in OEE from 82.7% to 86.2%. Ng *et al.* (2014) implemented the Six Sigma methodology, based on the DMAIC cycle, to mitigate the bottleneck that affected the performance of the OEE, in a semi-conductor manufacturer in Malaysia. Changing the fin design on the bearing shaft and on the two removable arms helped reduce equipment downtime by 6.5% and improved OEE from 70% to 80%, saving € 663,000 per year. Chiarini (2014) studied the implementation of autonomous maintenance in a motorcycle component manufacturer and observed a reduction in oil leakage on the factory floor, and, due to the definition of a fixed frequency for the maintenance or replacement of critical parts of the machines, a reduction in emissions of dust and smoke, such as volatile organic compounds and ammonia. Kumar Sharma and Gopal Sharma (2014) developed a framework based on TPM, focused on the implementation of performance indicators at the operational level, having been achieved, in a paper manufacturing cell, composed of two machines, PM-I and PM-II, improvements significant in the OEE (from 50% to 76% for PM-I and from 54% to 83% for PM-II), reduction in rework (from 22% to 10%), reduction in maintenance versus operating cost (from 30% to 10%) and reduction in the defect rate (from 24.82% to 5%). A new procedure was introduced for the circulation of information on planned inspections and revisions of machines in a production company, the main element of which is worksheets of the main machines participating in the production process. The effectiveness of the new procedure was subject to analysis comparing the working times and periods of inactivity of certain machines before and after implementation, and it was found that the availability of the examined machines increased by an average of 19%. The greatest reduction in the duration of inactivity periods was observed in failures and speed losses—an average of 7% and 5%, respectively (Zasadzień, 2015). The successful implementation of the TPM at a Bangladeshi printing and packaging plant was assessed and collected using a questionnaire, production data and factory complaint forms. It was found that the average downtime was reduced by 14.5% in the second year of TPM implementation, which shows the positive impact of implementing the methodology (Rahman, 2015). Chlebus *et al.* (2015) adapted TPM to the conditions of the mining industry, having developed a model based on three main pillars: improvement of the work environment, autonomous and planned maintenance and also the development of standards. This methodology was supported by 5S and continuous improvement. The implementation brought several benefits, among them, the increased safety of miners and the facilitation of repairs, thanks to the creation of work standards and the design of a special room for mechanics and high voltage operators. Chong *et al.* (2016) implemented autonomous maintenance in a semiconductor manufacturer, which contributed to the improvement of OEE, reducing performance losses and increasing the availability of equipment, providing the involvement of operators, with OEE increasing in the following 2 months, from 80% to 81.7%. Kuan Eng and Kam Choi (2016) investigated the relationship between OEE, throughput and costs associated with production based on a study carried out at a semiconductor manufacturing company located in Malaysia, in order to express and translate OEE into currency units. It was concluded that there is a very strong positive correlation between OEE and throughput. Based on this statistical evidence, when OEE increases, the yield will also increase, which in turn will lead to a reduction in production costs. It was possible to infer that the 1% increase in OEE will lead to an increase of 1.25% in throughput and a consequent reduction of 1.25% in production costs. Tang *et al.* (2016) implemented TPM in a printing company, with an availability increase from 58.33% to 70.83%. In addition, quality increased from 75% to 87.5% and performance also increased significantly from 78.57% to 82.35%. In short, the OEE of ABC Sdn Bhd equipment has been improved from 34.3% to 60% through the implementation of the TPM. The entire work environment was drastically changed and errors reduced with the implementation of the 5S. Finally, a suggestion was proposed to change the current production layout. TPM was implemented in a company in the food sector, in order to improve productivity and quality, involving machines, equipment, processes and employees, reducing delivery time and establishing a Lean environment. The implementation of the TPM resulted in an improvement in OEE, with reactive maintenance practices being reduced to less than 20% (Chundhoo *et al.*, 2018). In order to improve the efficiency of production equipment (Bataineh *et al.*, 2019), it was implemented a TPM through a model consisting of 13 sequential steps, in the beverage sector of the company. The efficiency of the glass line increased from 55.1% to 74.18%; line availability increased from 68.6% to 77.51%; quality was the parameter that suffered the lowest increase from 99.82 to 99.87% (0.05%). However, this corresponded to a significant reduction of 27.8% in the number of defective parts from 1,800 to 1,300 ppm; OEE increased from 35.27% to 57.42%, reaching the 50% target set by the KSCC. Díaz-contreras *et al.* (2020) developed a methodology that adjusts the final value of each of the OEE components based on costs (OEE AxC), having been applied in a metal-mechanical company, in a steel cutting machine. The values of the OEE components that have the highest incidence in costs decrease proportionately, with the most relevant component in costs having a greater impact on the calculation. In the case of the steel cutting machine, while with the traditional OEE method, a value of 89.61% was obtained, the proposed method generated a lower value (87.84%), giving more attention to prioritizing the improvement of components that have the greatest impact on costs for this machine. Abdelbar *et al.* (2019) proposed a new formulation of the OEE by using the combination of several methods especially, as a new quality evaluation approach for each activity of maintenance operational processes.

3. Methodology

To assess the resulting impact of the implementation of TPM practices on the operational performance of the Portuguese industries, a questionnaire-based survey method was used. To do this, the Google Forms platform was used, allowing the creation of a link, which was sent via email to all organizations invited to participate in the study.

The questionnaire consists of 10 questions, with special attention being paid to their development, in order to comply with three basic principles: the principle of clarity, which must be clear, concise and univocal; the principle of coherence, corresponding to the intention of the question itself and the principle of neutrality, which should not induce an answer but rather the liberation of the respondent from value judgments or the author's prejudice (Barbosa, 2012). Regarding the typology, we opted for questions of a mixed character, that is: open, in which, in addition to a set of closed options, there is also an open option, such as the "other" option; closed, in which all answer options are imposed, having resorted to multiple choice and also to the Likert scale, the latter being a methodology indicated for the realization of questionnaires or opinion polls, in which the respondents indicate their level of agreement in relation to a given statement, from a scale with several levels of classification, in order to be able to measure the intensity of the opinion in relation to a given topic (Joshi *et al.*, 2015). In the present study, a Likert scale based on five classification levels was used in order to assess the impact produced by the implementation of TPM practices on operational performance. The questionnaire was divided into two sections, as shown in Table 1. The first section intended to obtain a description of the company and the respondent who will answer the questionnaire, whereas the second section focused on investigating which of the lean tools had been implemented in the maintenance management by the respondent's organizations. In addition, Section 2 of the questionnaire aimed to identify the perception of the respondents in whether their companies had experienced any degree of impact in the operational measures of performance studied (quality, flexibility, productivity, safety and costs) from the implementation of the TPM practices, according to a set of characteristics or sentences, used for every single operational performance measure.

In order to validate all the questions developed, the questionnaire was sent to a small number of organizations, and, in an initial phase, the fifth question had been formulated as a yes/no question. However, it was possible to observe that some organizations, despite not having knowledge of the TPM, have implemented practices of the same methodology within the organization, having since then rectified the formulation of that question.

Data collection took place between August 12, 2020, and September 15, 2020, and a database of 472 organizations was constructed, resulting in a total of 97 responses, which equate to a response rate of approximately 21%, of which 84 were considered valid for the study, that is, those where it was possible to identify the implementation of TPM practices, so these answers constitute the sample of the study. The responses to the questionnaires were

Table 1.
Questionnaire overview and structure

Section	Questions
1	1. Identify the geographical location of the company 2. Identify the activity sector where the company labors 3. Identify the size of the company (micro; small; medium; large; very large) 4. Identify the number of maintenance operators (1–5; 6–10; 11–19; 20 or more)
2	5. Identify the TPM practices implemented in your company (Autonomous maintenance; Planned maintenance; Education and training; Focused improvement; Quality maintenance; Early equipment management; Safety, Health and Environment; TPM "Office") 6. Rate the impact resulting from the implementation of TPM practices within the scope of quality, based on the following statements or characteristics: Increased quality control in the manufacturing process; Increased compliance of the final product with customer specifications; Reduced the number of process defects and rejections; Reduced the number of customer complaints 7. Rate the impact of implementing TPM practices in the scope of flexibility, based on the following statements: Increased the ability to switch production quickly; Increased capacity to adjust production volume within a short period of time; Increased the ability to make changes to the product design after production starts; Increased capacity to change production planning 8. Rate the impact of implementing TPM practices in the scope of productivity, based on the following statements: Increased performance of maintenance operators; Increased equipment reliability; Reduced setup times and unplanned downtime; Reduced average maintenance time; Implementation and improvement of OEE 9. Rate the impact of implementing TPM practices in the scope of safety, based on the following statements: Increased the number of safe operating procedures in maintenance; Improved the health and safety of maintenance workers; Reduced the number of accidents at work in maintenance; Reduced the number of security breaches in maintenance
2	10. Rate the impact arising from the implementation of Lean practices within the scope of costs, based on the following statements: Reduced maintenance activity costs; Reduced maintenance inventory levels; Reduced maintenance labor costs; Reduced energy consumption in maintenance

automatically saved and later transferred to an Excel file, using the Google Forms platform, which facilitated the construction of a database, and, in turn, the statistical treatment of the data obtained.

4. Results analysis

The analysis of the data from the survey has been divided into two types of analysis: initially, a descriptive analysis will be performed, using Microsoft Excel®, in order to organize and summarize the data obtained. Then, an exploratory statistical analysis will be made, using the IBM Statistical Package for the Social Sciences (SPSS) software.

4.1 Descriptive statistical analysis

Regarding the demographical distribution of the organizations that make up the sample of this study, 52.38% are located in the North region, where the largest number of industrial companies in Portugal is located. A considerable number of organizations are located in the Center region (22.62%) and in the metropolitan area of Lisbon (19.05%), whereas only a small number are located in the other regions, such as Alentejo (3.57%), Algarve (1.19%) in the south and autonomous region of Madeira (1.19%), as shown in Figure 1.

The respondent organizations competed in many different sectors such as food (24.69%), automobile (19.75%), metalworking (9.88%), services (8.64%), medical and pharmaceutical (6.17%), aeronautics (4.94%), construction (3.70%), electrical/electronic components (3.70%), paper and cardboard (2.47%), packaging (2.47%), oil and fuel (2.47%), timber (1.23%), cork (1.23%), textile/clothing (1.23%), rope (1.23%), waste processing

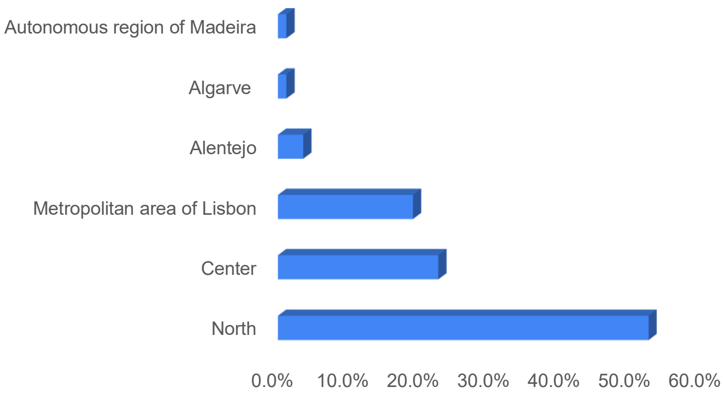

Figure 1.
Sample distribution according to the location of participant organizations

(1.23%), energy (1.23%), chemical (1.23%), cosmetic (1.23%) and leather goods (1.23%), as presented in Figure 2.

In terms of the dimension of the respondents' companies, it appears that the majority of the companies that participated in the study are, in general, of large dimensions, more specifically, 58% of them have 250 or more employees, whereas 25% have a medium size (between 50 and 249 employees), 13% are small (between 10 and 49 employees) and only 4% are micro-enterprises (between 1 and 9 employees), as shown in Figure 3.

With regard to the number of maintenance operators, 37% of the respondent companies have very large maintenance teams (with 20 or more operators), whereas 32% have average

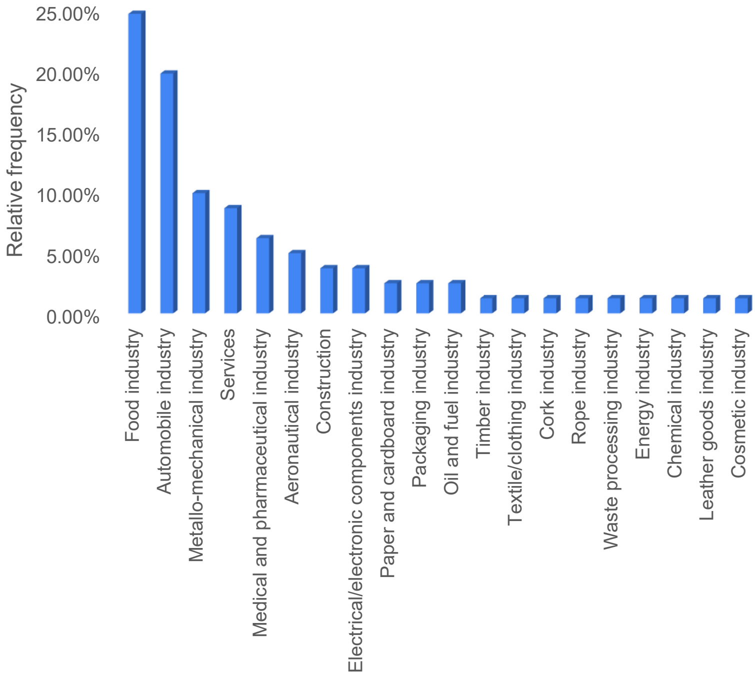

Figure 2.
Distribution of the sample according to the activity sector

maintenance teams (between 6 and 19 operators) and 31% of them have very small maintenance teams (with 5 or less operators), as presented in Figure 4.

Regarding the position that respondents occupy in their companies, it appears that the majority, more specifically, 45% of them exercise their function in the Maintenance department, which ends up strengthening the degree of veracity in relation to the answers obtained in the present study. A total of 27% of the respondents exercise their function in the Continuous Improvement department, whereas 16% are allocated to the Production department, 10% work in the Administration and 2% work in the Quality department, as shown in Figure 5.

In respect to the respondents' level of educational qualifications of the participants, it is possible to observe that the vast majority of respondents have a high level of education, as 47.62% have a master's degree, 28.57% have a degree, whereas 14.29% are postgraduate and 1.19% have a doctorate, according to Figure 6.

In what concerns to the assessment of the level of implementation of the TPM in the respondent organizations and also the degree of impact resulting from that same

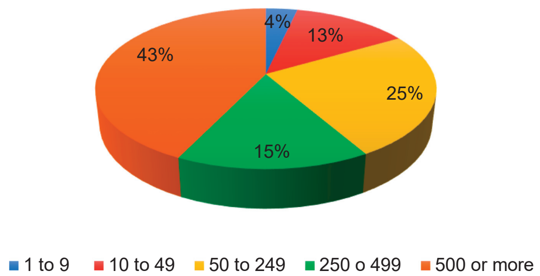

Figure 3.
Distribution of the sample according to the size of the organizations

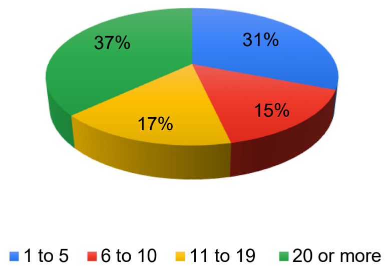

Figure 4.
Distribution of the sample according to the size of the maintenance team

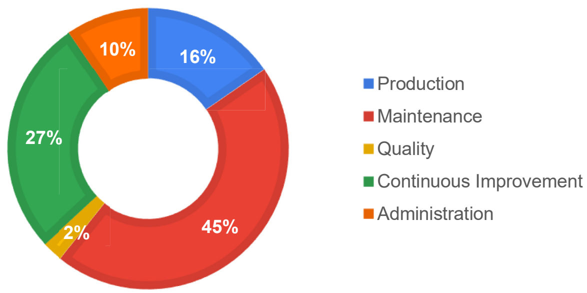

Figure 5.
Distribution of the sample according to the department in which the respondent performs his function

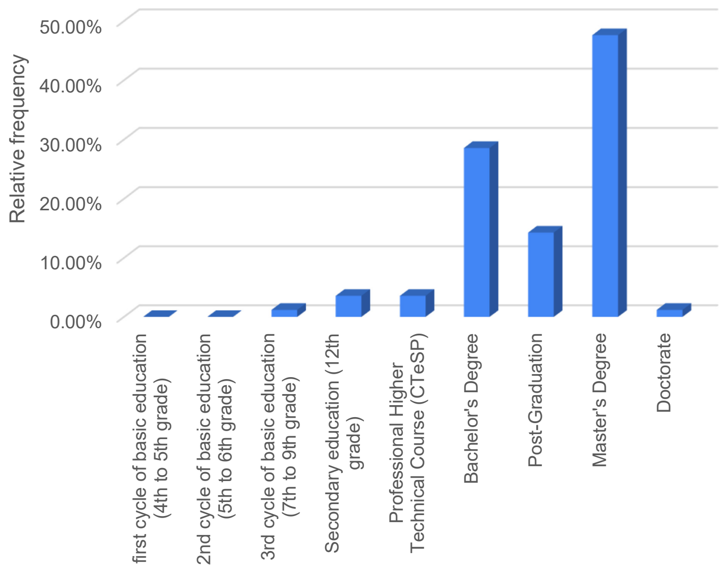

Figure 6. Distribution of the sample according to the respondents' qualifications

implementation in the operational performance, it was possible to verify that the totality of the organizations that participated in the study had at least implemented one TPM practice.

According to Table 2, it is observed that:

(1) Planned maintenance was the practice most frequently implemented by the organizations that participated in the study.

(2) The practices: planned maintenance, education and training, together with specific improvement, are implemented in more than two-thirds of the organizations surveyed.

(3) TPM "Office" is the practice with the lowest level of implementation, below 21%.

According to Table 2, regarding the number of TPM practices implemented in each organization, it can be seen that most of the organizations that make up the sample of the present study have three TPM practices implemented, that is planned maintenance; education and training; and focused improvement, whereas only 6 of the 84 organizations have only one practice implemented, that is planned maintenance (Figure 7).

Regarding the impact assessment resulting from the implementation of TPM practices, and as mentioned before, this was evaluated according to five metrics of operational

TPM practice	Absolute frequency	Relative frequency (%)
1 -Planned maintenance	73	86.9
2 -Education and training	59	70.2
3 -Focused Improvement	57	67.9
4 -Autonomous maintenance	55	65.5
5 -Safety, Health and Environment	54	64.3
6 -Early equipment management	39	46.4
7 -Quality maintenance	30	35.7
7 -TPM "Office"	17	20.2

Table 2. Degree of implementation of TPM practices in organizations

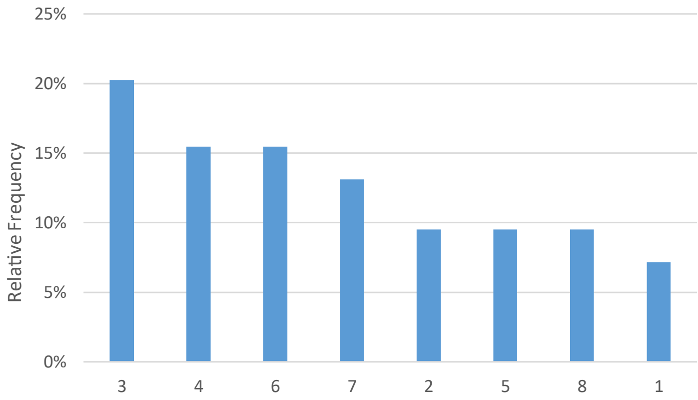

Figure 7. Number of TPM practices implemented simultaneously in each organization

performance, namely, quality, flexibility, productivity, safety and costs. For this effect, a Likert scale based on five classification levels was used ("very low", "low", "moderate", "high" and "very high") and it was converted to a quantitative ordinal scale, from 1 to 5 (Likert, 1932). From the data presented in Table 3, it appears that all characteristics related to quality have suffered an impact above the "moderate" level, being the reduction in the number of defects and rejections in the process the characteristic that presents, on average, a higher impact value and also the least variability between the four characteristics, which strengthens its position as the one that obtained the most positive results.

From the data presented in Table 4, it appears that all the characteristics related to flexibility have an impact above the "moderate" level, being the increase in the capacity to change production planning the characteristic that presents, on average, a higher impact value and also the least variability among the four characteristics, which strengthens its position as the one that obtained the most positive results.

From the data presented in Table 5, it appears that all the characteristics related to productivity have an impact above the "moderate" level, being the increase in the reliability of

Table 3. Average impact level of the implementation of TPM practices for each characteristic of the quality dimension

	Increased quality control in the production process	Increased compliance of the final product with customer specifications	Reduction in the number of defects and process rejections	Reduction in the number of customer complaints
Mean	3.49	3.44	3.59	3.43
Standard Deviation	1,143	1,188	1,046	1,171

Table 4. Average impact level of the implementation of TPM practices for each characteristic of the flexibility dimension

	Increased ability to switch production quickly	Increased ability to adjust production volume within a short period of time	Increased ability to make changes to product design after production starts	Increased ability to change production planning
Mean	3.36	3.38	3.08	3.51
Standard deviation	1,154	1,107	1,176	1,113

the equipment the characteristic that presents, on average, a higher impact value, and at the same time, one of the least variability among the five characteristics, which strengthens its position as the one that obtained the most positive results.

From the data presented in Table 6, it appears that all safety-related characteristics have an impact above the “moderate” level, with the increase in the number of safe operational procedures in maintenance presenting, on average, a higher impact value and also one of the lowest values of variability among the four characteristics, which strengthens its position as the one that obtained the most positive results.

From the data presented in Table 7, it appears that all the characteristics related to costs have an impact above the “moderate” level, with the reduction of maintenance inventory levels presenting, on average, a higher impact value and also the lower value of variability between the four characteristics, which strengthens its position as the one that obtained the most positive results.

4.2 Inferential statistical analysis

In order to deepen the knowledge about Lean and PMS practices in the Portuguese industry, the results were extrapolated, obtained through descriptive analysis, and several types of tests were carried out with the aim of relating the different variables.

4.2.1 Analysis of internal consistency using Cronbach’s alpha. In order to assess the characteristics that make up each of the dimensions of operational performance, an analysis

	Increased performance of maintenance operators	Increased equipment reliability	Reduction of setup times and unplanned downtime	Reduced average maintenance time	Implementation and improvement of OEE
Mean	3.53	3.69	3.64	3.47	3.51
Standard deviation	1,088	1,134	1,093	1,107	1,061

Table 5. Average impact level of the implementation of TPM practices for each characteristic of the productivity dimension

	Increase in the number of safe operating procedures in maintenance	Improving the health and safety of maintenance workers	Reduction in the number of occupational accidents in maintenance	Reduction in the number of security breaches in maintenance
Mean	3.37	3.45	3.27	3.43
Standard deviation	1,136	1,131	1,193	1,187

Table 6. Average impact level of the implementation of TPM practices for each characteristic of the safety dimension

	Reduced maintenance costs	Reduced maintenance inventory levels	Reduction of maintenance labor costs	Reduction of energy consumption in maintenance
Mean	3.28	3.31	3.21	3.24
Standard deviation	1,141	1,083	1,087	1,169

Table 7. Average impact level of the implementation of TPM practices for each characteristic of the costs dimension

of internal consistency was carried out. The alpha index seeks to describe the extent to which items in a given set measure the same dimension or construct, being directly related to the relationship between those same items, varying numerically between 0 and 1 (Tavakol and Dennick, 2011). The greater the correlations between the items, the greater the homogeneity of the items and, in turn, the greater the consistency with which they measure the same dimension or construct. On the other hand, the internal consistency estimates the reliability of a set, since the lower the variability of the same item in a sample, the smaller the associated measurement error, and, thus, the closer the coefficient will be to 1, meaning that the set is more consistent (Maroco and Garcia-Marques, 2006). Thus, the test was performed only for the answers to Questions 6–10, based on the Likert scale and whose answers were coded on a quantitative ordinal scale from 1 to 5 in the software SPSS. Regarding the group of questions inserted in the scope of the TPM practices, for the 21 characteristics evaluated by the 66 participants, an alpha value equal to 0.978 was obtained (Figure 8).

Thus, comparing the value obtained for the group of questions with the values presented in Table 8, it appears that the level of internal consistency of the selected questions is excellent.

4.2.2 Hypothesis testing. In order to assess the relationship between the variables, hypothesis tests were used. In order to study the impact resulting from the implementation of TPM practices, five new variables were created for each of the operational performance dimensions, by calculating the arithmetic mean of the values obtained for the characteristics that make up each of the studied dimensions.

Taking into account the data obtained through the questionnaire, the following tests were carried out:

(1) Differences in the number of company employees regarding the impact of TPM practices

It was decided to verify whether their impact differs or not depending on the size of the organizations. Thus, the chosen test was the Kruskal–Wallis non-parametric test, used to

Case Processing Summary

		N	%
Cases	Valid	66	78.6
	Excluded [a]	18	21.4
	Total	84	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.978	21

Figure 8.
Value obtained for Cronbach's alpha in relation to the group of questions within the scope of TPM practices through SPSS

Table 8.
Internal consistency level according to Cronbach's alpha value

Alpha value	Internal consistency
Less than 0.5	Unacceptable
Between 0.5 and 0.6	Poor
Between 0.6 and 0.7	Questionable
Between 0.7 and 0.8	Acceptable
Between 0.8 and 0.9	Good
Between 0.9 and 1	Excellent

Source(s): Adapted from George and Mallery (2019) compare three or more populations, in order to verify whether all populations follow the same distribution or whether there are differences in at least two of the populations at the level of distribution (McKight and Najab, 2010). Having verified that the groups "micro" and "small" companies dimension was well below the dimension of other groups, these groups were aggregated, in order to avoid significant differences between the groups and enabling the viability of the statistical tests.

The following research hypothesis was formulated:

H0. Kruskal–Wallis test only evaluates if the distribution of TPM practices is the same (or not) across categories of "number of company employees."

In terms of quality, it is observed that the result presented is lower than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is rejected, with evidence that there are differences between groups. Analyzing the average ranking for the number of employees in the organization, it appears that microenterprises and small enterprises are those in which the impact resulting from the implementation of TPM practices is higher, in the dimension of quality (Figure 9).

In terms of flexibility, it is observed that the result presented is lower than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is rejected, with evidence that there are differences between groups. Analyzing the average ranking for the number of employees in the organization, it appears that microenterprises and big enterprises are those in which the impact resulting from the implementation of TPM practices is greater, in the dimension of flexibility (Figure 10).

In terms of productivity, it is observed that the result presented is greater than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is not rejected, with no evidence that there are differences between groups (Figure 11).

Ranks

	number of company employees	N	Mean Rank
tpm_quality	1 to 49	13	48.12
	50 to 249	18	25.92
	250 to 499	10	40.35
	500 or more	35	40.87
	Total	76	

Test Statistics[a,b]

	tpm_quality
Kruskal-Wallis H	9.078
df	4
Asymp. Sig.	0.025

a. Kruskal Wallis Test

b. Grouping Variable: number of company employees

Figure 9. Result of the Kruskal–Wallis test for the number of employees of the company regarding the dimension of quality, within the scope of the implementation of the TPM practices

Ranks

	number of company employees	N	Mean Rank
tpm_flexibility	1 to 49	13	46.65
	50 to 249	18	26.94
	250 to 499	10	48.60
	500 or more	33	36.29
	Total	74	

Test Statistics[a,b]

	tpm_flexibility
Kruskal-Wallis H	9.598
df	3
Asymp. Sig.	0.022

a. Kruskal Wallis Test

b. Grouping Variable: number of company employees

Figure 10. Result of the Kruskal–Wallis test for the number of employees of the company regarding the dimension of flexibility, within the scope of the implementation of the TPM practices

In terms of safety, it is observed that the result presented is greater than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is not rejected, with no evidence that there are differences between groups (Figure 12).

In terms of costs, it is observed that the result presented is higher than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is not rejected, with no evidence that there are differences between groups (Figure 13).

(2) Differences in the number of maintenance operators regarding the impact of TPM practices

It was decided to verify whether their impact differs or not depending on the size of the maintenance teams of the organizations. Thus, the chosen test was, once again, the Kruskal–Wallis non-parametric test.

Ranks

	number of company employees	N	Mean Rank
tpm_productivity	1 to 49	13	42.58
	50 to 249	18	27.14
	250 to 499	10	41.50
	500 or more	32	38.88
	Total	73	

Test Statistics[a,b]

	tpm_flexibility
Kruskal-Wallis H	5.575
df	3
Asymp. Sig.	0.134

a. Kruskal Wallis Test

b. Grouping Variable: number of company employees

Figure 11. Result of the Kruskal–Wallis test for the number of employees of the company regarding the dimension of productivity, within the scope of the implementation of the TPM practices

Ranks

	number of company employees	N	Mean Rank
tpm_safety	1 to 49	13	42.88
	50 to 249	19	32.21
	250 to 499	11	47.14
	500 or more	32	36.31
	Total	75	

Test Statistics[a,b]

	tpm_safety
Kruskal-Wallis H	4.188
df	3
Asymp. Sig.	0.242

a. Kruskal Wallis Test

b. Grouping Variable: number of company employees

Figure 12. Result of the Kruskal–Wallis test for the number of employees of the company regarding the dimension of safety, within the scope of the implementation of the TPM practices

Ranks

	number of company employees	N	Mean Rank
tpm_costs	1 to 49	12	44.92
	50 to 249	19	28.05
	250 to 499	11	46.27
	500 or more	31	36.13
	Total	73	

Test Statistics[a,b]

	tpm_costs
Kruskal-Wallis H	7.349
df	3
Asymp. Sig.	0.062

a. Kruskal Wallis Test

b. Grouping Variable: number of company employees

Figure 13. Result of the Kruskal–Wallis test for the number of employees of the company regarding the dimension of costs, within the scope of the implementation of the TPM practices

The following research hypothesis was formulated:

H1. Kruskal–Wallis test only evaluates if the distribution of TPM practices is the same (or not) across categories of "number of maintenance operators."

In terms of quality, it is observed that the result presented is lower than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is rejected, with evidence that there are differences between groups.

Analyzing the average ranking for the number of maintenance operators, it appears that organizations that have very small or large maintenance teams are those in which the impact resulting from the implementation of TPM practices is higher, in the dimension of quality (Figure 14).

In terms of flexibility, it is observed that the result presented is greater than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is not rejected, with no evidence that there are differences between groups (Figure 15).

In terms of productivity, it is observed that the result presented is higher than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is not rejected, with no evidence that there are differences between groups (Figure 16).

In terms of safety, it is observed that the result presented is higher than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is not rejected, with no evidence that there are differences between groups (Figure 17).

In terms of costs, it is observed that the result presented is higher than the probability of the test statistic, which is equal to 0.05, so the null hypothesis is not rejected, with no evidence that there are differences between groups (Figure 18).

4.2.3 Factor analysis. Factorial analysis is a multivariate analysis technique, which seeks to reduce a large number of variables observed in a smaller number of factors, these being the linear combination of the original variables (Filho and Júnior, 2009), having been applied to

Ranks

	number of maintenance operators	N	Mean Rank
tpm_quality	1 to 5	22	41.80
	6 to 10	13	39.42
	11 to 19	12	22.25
	20 or more	29	42.31
	Total	76	

Test Statistics[a,b]

	tpm_quality
Kruskal-Wallis H	8.139
df	3
Asymp. Sig.	0.043

a. Kruskal Wallis Test

b. Grouping Variable: number of maintenance operators

Figure 14. Result of the Kruskal–Wallis test for the number of maintenance operators regarding the dimension of quality, within the scope of the implementation of the TPM practices

Ranks

	number of maintenance operators	N	Mean Rank
tpm_flexibility	1 to 5	22	37.43
	6 to 10	13	42.08
	11 to 19	11	31.77
	20 or more	28	37.68
	Total	74	

Test Statistics [a,b]

	tpm_flexibility
Kruskal-Wallis H	1.391
df	3
Asymp. Sig.	0.708

a. Kruskal Wallis Test

b. Grouping Variable: number of maintenance operators

Figure 15. Result of the Kruskal–Wallis test for the number of maintenance operators regarding the dimension of flexibility, within the scope of the implementation of the TPM practices

the set of questions corresponding to the evaluation of the implemented TPM practices (Questions 6–10).

Bartlett's sphericity test was performed, with the goal of evaluating the hypothesis that the correlation matrix presents significant correlations between at least some variables, and also the Kaiser–Meyer–Olkin test (KMO) that classifies the amount of variance shared between the items, which is explained by latent factors (Lara, 2019), in order to validate the factor analysis.

Regarding Bartlett's sphericity test, and according to Figure 19, a significance value of less than 0.05 was obtained, so the null hypothesis, which states that there is no correlation between the variables, should be rejected, at least that the data follow a multivariate distribution and are acceptable for the analysis of main components. A value of 0.922 was obtained for the KMO index, which, according to the values presented in Table 9, constitutes a very good value for carrying out the factor analysis.

Ranks

	number of maintenance operators	N	Mean Rank
tpm_productivity	1 to 5	22	35.00
	6 to 10	11	44.68
	11 to 19	12	31.33
	20 or more	28	37.98
	Total	73	

Test Statistics[a,b]

	tpm_productivity
Kruskal-Wallis H	2.595
df	3
Asymp. Sig.	0.458

a. Kruskal Wallis Test

b. Grouping Variable: number of maintenance operators

Figure 16. Result of the Kruskal–Wallis test for the number of maintenance operators regarding the dimension of productivity, within the scope of the implementation of the TPM practices

Ranks

	number of maintenance operators	N	Mean Rank
tpm_safety	1 to 5	21	36.12
	6 to 10	13	41.81
	11 to 19	12	32.21
	20 or more	29	40.05
	Total	75	

Test Statistics[a,b]

	tpm_safety
Kruskal-Wallis H	1.685
df	3
Asymp. Sig.	0.640

a. Kruskal Wallis Test

b. Grouping Variable: number of maintenance operators

Figure 17. Result of the Kruskal–Wallis test for the number of maintenance operators regarding the dimension of safety, within the scope of the implementation of the TPM practices

Ranks

	number of maintenance operators	N	Mean Rank
tpm_costs	1 to 5	22	35.98
	6 to 10	11	40.59
	11 to 19	12	29.38
	20 or more	28	39.66
	Total	73	

Test Statistics[a,b]

	tpm_costs
Kruskal-Wallis H	2.404
df	3
Asymp. Sig.	0.493

a. Kruskal Wallis Test

b. Grouping Variable: number of maintenance operators

Figure 18. Result of the Kruskal–Wallis test for the number of maintenance operators regarding the dimension of costs, within the scope of the implementation of the TPM practices

The first output obtained regarding the performed factor analysis is a table of the explained total variance, so the sum of the eigenvalues cannot exceed the total number of components, which correspond to the 21 characteristics. From Table 10, it is possible to verify that the SPPS software extracted two components, according to the theoretical criterion of the eigenvalue greater than 1, and these same components are responsible for approximately 76% of the total variance of the variables initially defined.

Thereafter, the component matrix is presented, which establishes a relationship between the 21 characteristics and the two components extracted in the analysis. Table 11 shows that all characteristics are related to the first component, which does not allow us to draw any conclusions.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.922
Bartlett's Test of Sphericity	Approx. Chi-Square	1706.500
	df	210
	Sig.	0.000

Figure 19.
Result of the KMO and Bartlett's test

KMO Index	Factor analysis
Less than 0.5	Unacceptable
Between 0.5 and 0.6	Bad
Between 0.6 and 0.7	Average
Between 0.7 and 0.8	Reasonable
Between 0.8 and 0.9	Good
Greater than 0.9	Very good

Table 9.
Validation of the factor analysis using the value obtained for the KMO index

Component	Total	Initial Eigenvalues % of Variance	Cumulative %
1	14,736	70,173	70,173
2	1.170	5.571	75,744
3	0.842	4.008	79,753
4	0.766	3.646	83,399
5	0.668	3.183	86,582
6	0.478	2.274	88,856
7	0.348	1.657	90,513
8	0.320	1.522	92,035
9	0.246	1.172	93,208
10	0.237	1.128	94,336
11	0.178	0.848	95,184
12	0.175	0.835	96,019
13	0.172	0.820	96,839
14	0.143	0.682	97,522
15	0.126	0.599	98,121
16	0.114	0.541	98,662
17	0.078	0.371	99,033
18	0.067	0.317	99,350
19	0.063	0.299	99,649
20	0.043	0.207	99,856
21	0.030	0.144	100,000

Table 10.
Result obtained for the total variance of the components by the first method

Table 11.
Components matrix obtained by the first method

Component matrix[1]

	Component 1	Component 2
Increased quality control in the production process	0.850	−0.090
Increased compliance of the final product with customer specifications	0.829	−0.245
Reduction in the number of process defects and rejections	0.834	0.009
Reduction in the number of customer complaints	0.799	−0.297
Increased ability to switch production quickly	0.820	0.326
Increased ability to adjust production volume within a short period of time	0.855	0.181
Increased ability to make changes to product design after production starts	0.767	0.080
Increased ability to change production planning	0.809	0.378
Increased performance of maintenance operators	0.849	0.132
Increased equipment reliability	0.804	0.281
Reduction of setup times and unplanned downtime	0.868	0.259
Reduced average maintenance time	0.874	0.079
Implementation and improvement of OEE	0.774	0.312
Increased number of safe operating procedures in maintenance	0.884	−0.343
Improved health and safety of maintenance workers	0.903	−0.261
Reduction in the number of occupational accidents in maintenance	0.799	−0.389
Reduction in the number of security breaches in maintenance	0.868	−0.340
Reduced maintenance costs	0.822	0.059
Reduction of maintenance inventory levels	0.802	−0.008
Reduced maintenance labor costs	0.882	−0.038
Reduced energy consumption in maintenance	0.882	−0.019

Note(s): Extraction Method: Principal Component Analysis
[1]. 2 components extracted

In this way, a rotation was applied to the component matrix, as shown in Table 12, in order to divide the set of variables defined in subsets, aiming at the greatest possible degree of independence.

The 21 characteristics were then attached to each of the components, according to the greatest possible weight and greater than 0.5. Thus, it is observed that:

(1) The first component aggregated all the four characteristics that compose the "flexibility" dimension, as well as the five characteristics that compose the "productivity" dimension. It also aggregated one of the four characteristics regarding the "quality" dimension, namely, the "Reduction in the number of process defects and rejections" as well as one of the four characteristics regarding the "costs" dimension, namely, the "Reduced maintenance costs";

(2) The second component aggregated all the four characteristics inserted in the "safety" dimension, as well as three of the four characteristics inserted in the "quality" dimension and three of the four characteristics inserted in the "costs" dimension.

Not satisfied with the results obtained, a new factor analysis was carried out, using a second method, with the forced extraction of five components, in order to validate the five dimensions considered.

Starting from the explained total variance table, it was found that the five components are responsible for approximately 87% of the total variance of the variables initially defined (Table 13), which represents an increase in the explanatory power of approximately 11%, compared to that obtained in the previous factor analysis.

Again, the component matrix was obtained, and, as shown in Table 14, all the characteristics are related to the first component, which does not allow us to draw any conclusions.

Rotated component matrix[1]

	Component 1	Component 2
Increased quality control in the production process	0.544	0.659
Increased compliance of the final product with customer specifications	0.421	0.755
Reduction in the number of process defects and rejections	0.602	0.577
Reduction in the number of customer complaints	0.363	0.771
Increased ability to switch production quickly	0.814	0.341
Increased ability to adjust production volume within a short period of time	0.738	0.469
Increased ability to make changes to product design after production starts	0.604	0.479
Increased ability to change production planning	0.843	0.296
Increased performance of maintenance operators	0.699	0.500
Increased equipment reliability	0.771	0.362
Reduction of setup times and unplanned downtime	0.802	0.422
Reduced average maintenance time	0.680	0.555
Implementation and improvement of OEE	0.771	0.319
Increased number of safe operating procedures in maintenance	0.391	0.863
Improved health and safety of maintenance workers	0.463	0.818
Reduction in the number of occupational accidents in maintenance	0.299	0.837
Reduction in the number of security breaches in maintenance	0.382	0.850
Reduced maintenance costs	0.629	0.533
Reduction of maintenance inventory levels	0.557	0.567
Reduced maintenance labor costs	0.603	0.644
Reduced energy consumption in maintenance	0.616	0.631

Note(s): Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization
[1]. Rotation converged in three iterations

Table 12. Component matrix generated after rotation, by the first method

Component	Total	Initial Eigenvalues % of Variance	Cumulative %
1	14,736	70,173	70,173
2	1.170	5.571	75,744
3	0.842	4.008	79,753
4	0.766	3.646	83,399
5	0.668	3.183	86,582
6	0.478	2.274	88,856
7	0.348	1.657	90,513
8	0.320	1.522	92,035
9	0.246	1.172	93,208
10	0.237	1.128	94,336
11	0.178	0.848	95,184
12	0.175	0.835	96,019
13	0.172	0.820	96,839
14	0.143	0.682	97,522
15	0.126	0.599	98,121
16	0.114	0.541	98,662
17	0.078	0.371	99,033
18	0.067	0.317	99,350
19	0.063	0.299	99,649
20	0.043	0.207	99,856
21	0.030	0.144	100,000

Table 13. Result obtained for the total variance of the components by the second method

Component matrix[1]			Component		
	1	2	3	4	5
Increased quality control in the production process	0.850	−0.090	0.242	−0.268	0.038
Increased compliance of the final product with customer specifications	0.829	−0.245	0.376	−0.149	0.049
Reduction in the number of process defects and rejections	0.834	0.009	0.299	−0.275	0.099
Reduction in the number of customer complaints	0.799	−0.297	0.364	0.033	−0.013
Increased ability to switch production quickly	0.820	0.326	0.114	0.032	−0.303
Increased ability to adjust production volume within a short period of time	0.855	0.181	0.018	0.121	−0.229
Increased ability to make changes to product design after production starts	0.767	0.080	0.181	0.447	−0.182
Increased ability to change production planning	0.809	0.378	0.034	0.037	−0.263
Increased performance of maintenance operators	0.849	0.132	−0.276	−0.203	−0.007
Increased equipment reliability	0.804	0.281	−0.171	−0.271	0.139
Reduction of setup times and unplanned downtime	0.868	0.259	−0.086	−0.091	−0.056
Reduced average maintenance time	0.874	0.079	−0.083	−0.121	0.119
Implementation and improvement of OEE	0.774	0.312	−0.061	0.057	0.244
Increased number of safe operating procedures in maintenance	0.884	−0.343	−0.135	−0.018	−0.077
Improved health and safety of maintenance workers	0.903	−0.261	−0.143	−0.119	−0.103
Reduction in the number of occupational accidents in maintenance	0.799	−0.389	−0.305	0.152	−0.092
Reduction in the number of security breaches in maintenance	0.868	−0.340	−0.249	−0.033	−0.151
Reduced maintenance costs	0.822	0.059	−0.096	0.127	0.356
Reduction of maintenance inventory levels	0.802	−0.008	0.032	0.398	0.365
Reduced maintenance labor costs	0.882	−0.038	−0.153	0.093	0.038
Reduced energy consumption in maintenance	0.882	−0.019	0.148	0.123	0.053

Note(s): Extraction Method: Principal Component Analysis
[1]. Five components extracted

Table 14. Components matrix obtained by the second method

In this way, a rotation was applied to the component matrix, as shown in Table 15, in order to divide the set of variables defined in subsets, aiming at the greatest possible degree of independence.

The 21 characteristics were then attached to each of the components, according to the greatest possible weight. Thus, it is observed that:

(1) The first component aggregated all the four characteristics that compose the "safety" dimension. It also aggregated one of the four characteristics regarding the "costs" dimension, namely, the "Reduced maintenance labor costs";

(2) The second component aggregated all the five characteristics inserted in the "productivity" dimension;

(3) The third component aggregated all the five characteristics inserted in the "productivity" dimension, as well as one of the four characteristics inserted in the "costs" dimension, namely, the "Reduced energy consumption in maintenance";

(4) The fourth component aggregated all the four characteristics that compose the "flexibility" dimension;

(5) The fifth component aggregated two of the four characteristics that compose the "costs" dimension.

Rotated component matrix[1]	Component				
	1	2	3	4	5
Increased quality control in the production process	0.324	0.429	0.698	0.250	0.153
Increased compliance of the final product with customer specifications	0.346	0.228	0.796	0.236	0.230
Reduction in the number of process defects and rejections	0.207	0.472	0.709	0.258	0.189
Reduction in the number of customer complaints	0.397	0.077	0.718	0.305	0.296
Increased ability to switch production quickly	0.219	0.430	0.311	0.735	0.127
Increased ability to adjust production volume within a short period of time	0.365	0.378	0.279	0.649	0.238
Increased ability to make changes to product design after production starts	0.306	0.060	0.279	0.692	0.455
Increased ability to change production planning	0.212	0.488	0.232	0.713	0.152
Increased performance of maintenance operators	0.471	0.689	0.216	0.296	0.158
Increased equipment reliability	0.256	0.782	0.263	0.247	0.202
Reduction of setup times and unplanned downtime	0.319	0.622	0.277	0.477	0.217
Reduced average maintenance time	0.387	0.592	0.369	0.273	0.308
Implementation and improvement of OEE	0.156	0.595	0.211	0.329	0.482
Increased number of safe operating procedures in maintenance	0.746	0.288	0.417	0.237	0.233
Improved health and safety of maintenance workers	0.708	0.391	0.427	0.261	0.159
Reduction in the number of occupational accidents in maintenance	0.836	0.190	0.205	0.218	0.298
Reduction in the number of security breaches in maintenance	0.815	0.312	0.323	0.250	0.165
Reduced maintenance costs	0.334	0.491	0.276	0.179	0.609
Reduction of maintenance inventory levels	0.312	0.256	0.286	0.264	0.788
Reduced maintenance labor costs	0.536	0.424	0.274	0.341	0.392
Reduced energy consumption in maintenance	0.363	0.311	0.480	0.414	0.432

Note(s): Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization
[1]. Rotation converged in nine iterations

Table 15. Component matrix generated after rotation, by the second method

With the results obtained in the present factor analysis, it turns out that it was possible to obtain a more adjusted model compared to the one obtained with the first method, having validated four out of the five dimensions considered in this study, with the exception of the "costs" dimension, given that two of the four characteristics were aggregated to different components.

5. Discussion

The main goal of the present study was to identify and explore the role of TPM practices in Portuguese companies, focusing on their impact on the operational performance. Belekoukias *et al.* (2014) investigated the impact of many methods and tools on the measures of operational performance of 140 manufacturing organizations around the world, having found that TPM does not have a significant impact on quality, flexibility and costs dimensions, which the authors assigned to the lack of an effective and full TPM implementation. Sahoo and Yadav (2020) conducted a study along with Indian manufacturing companies, in order to study the impact of TPM in the operational performance parameters, having observed that, in general, the registered levels were inferior to the ones obtained in this study: quality (2.49–3.49); productivity (2.52–3.57); safety (2.65–3.38) and costs (2.77–3.26). Aiming to measure the impact of TPM on the level of JIT production implementation and performance (Abdallah and Matsui, 1973), developed multi-item scales, having recorded identical levels to the ones in the present study: quality (3.86 to 3.49); flexibility (3.83 to 3.33) and costs (3.27 to 3.26). In order to provide empirical evidence on TPM contribution to improve business performance in the context of the Indian manufacturing industry (Seth and Tripathi, 2006), developed a questionnaire-based survey, having obtained somewhat similar results to the ones in the present investigation: quality (3.61–3.49); productivity (3.52–3.57); safety (4.08–3.38) and costs (2.98–3.26).

6. Conclusion

According to the data collected, and after an extensive statistical analysis, it was found that the planned maintenance, together with education and training are the practices with the highest degree of implementation in the Portuguese industry, exceeding 70% for both. It was found that TPM practices produced a positive impact on the operational performance of the respondent companies, since the impact produced by the implementation of TPM practices is, in general, "moderate" for all dimensions of operational performance, with productivity being the dimension with a higher degree of impact and costs the dimension that suffered a lesser impact from the implementation of TPM practices. However, these results, despite not going in hand with the common knowledge (cost is inversely proportional to productivity), only classify the degree of the impact produced by TPM practices, so it is not possible to draw any kind of correlation between the dimensions considered.

Regarding the hypothesis tests, carried out with the aim of identifying possible associations between the variables, it was found, through the Kruskal–Wallis test, that there are differences regarding the impact produced by the implementation of Lean practices in the management of maintenance at the level of the number of employees, in the dimensions of productivity and costs, whereas, with regard to the impact produced by the implementation of TPM practices for the same variable, there are differences in the dimensions of quality and flexibility. Regarding the level of impact produced by the implementation of TPM practices in relation to the size of maintenance teams, it was found that there are only differences in the dimension of quality.

7. Research outcomes

(1) Despite the fact that Planned Maintenance, alongside Education and Training are vastly implemented in the Portuguese enterprises (registered an implementation degree higher than 70%), the remaining TPM practices had a somewhat low to average implementation level, which may be due to the absence of a sustained cultural transformation (which may lead to worker resistance) in those enterprises, with the TPM practices being implemented in an individual basis, instead of a whole approach. The lack of top management support, coupled with the absence of a proper employee involvement (based on training, empowerment and rewarding/incentive of the working force) are some of the factors that can explain, in part, the effect of the TPM practices in the operational performance, which was found to be moderate for all the five dimensions considered.

(2) The results of the present study can be a solid reference for the top and maintenance management of Portuguese companies alongside, presenting the current status regarding the implementation and effectiveness of TPM practices on the operational performance, in order to provide a basis to adopt and improve their knowledge of lacking TPM practices and their potential, helping them to plan, prepare and deploy the TPM methodology in a lasting and fructiferous way.

8. Future research

As a proposal for future work, and in order to complement the present study, new variables should be introduced, such as the state of maturity of TPM practices implementation, which can play a vital role in their effectiveness.

In the same way, other performance metrics should be considered in addition to those that were considered in this work, focusing on organizational performance. The range of maintenance management strategies should also be extended, including Reliability Centered Maintenance (RCM) and Condition-Based Maintenance (CBM), among others.

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