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Facing Challenges of Implementing Total Productive Management and Lean Tools in Manufacturing Enterprises

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Abstract: Manufacturing companies are always looking for ways to outperform their competitors. They are constantly trying to improve their efficiency and reduce costs. One method that improves efficiency and maximises the availability of production equipment is total productive maintenance (TPM), which is a lean optimisation philosophy tool that focuses on the optimisation of maintenance. Although TPM is known for improving maintenance, there are many obstacles to its successful implementation. Failure to properly implement TPM can result in additional costs and lost time, and it can have a negative impact on employees. For these reasons, a survey was prepared and conducted among several companies, each involved in a different field of work and having a different number of employees. The main findings of this research are the key factors that can negatively impact the implementation of TPM and lean tools in general, as well as suggestions for improvements that can ensure their successful implementation and sustainability. An analysis was conducted based on the size of each company as well as the job roles within them. The study covers issues that may arise during the implementation of TPM and other lean tools at all levels of the hierarchy in an enterprise and provides guidance on how to manage situations that may prevent the successful application of TPM.

Keywords: implementation; TPM; lean; problems; sustainability

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1. Introduction

Total productive maintenance (TPM), as an aspect of lean principles for the optimisation of production, is a valuable and constructive tool for improving the overall quality of maintenance, thus increasing the lifetime, reliability, and efficiency of production equipment. Workplace organisation, procedures, and maintenance times can be improved significantly as well [1]. Defined another way, TPM is a plant improvement methodology that enables continuous and rapid improvements to manufacturing processes through employee involvement, employee empowerment, and closed-loop measurement of the results, and that is incorporated into the concept of preventive maintenance [2]. TPM's implementation means striving towards a vision of the ideal manufacturing situation, a vision that encompasses zero breakdowns, zero defects, zero abnormalities, and zero accidents [3].

However, if TPM is incorrectly implemented or maintained, it can have a negative impact on maintenance procedures, workers' motivation, and the reliability of production equipment, as well as increase workloads. To properly introduce TPM into a company, not only must the steps for its implementation be respected but also the mental aspects related to the workers who are included in the entire process [4]. With the successful implementation of TPM, the availability, efficiency, and reliability of production equipment will increase, which are the three main indicators of equipment performance. Availability is the proportion of time that the equipment can be used for its intended purpose. Reliability describes how often equipment does not fulfil its intended purpose. Efficiency is the ratio of the actual output of a machine (i.e., products of desired quality) to its rated output during the time that it is operational [5]. The goal is to increase these properties without increasing the workload, namely, by reorganising efforts more efficiently. With today's requirements of advanced production with minimum waste and considering the ever-growing competition, manufacturers need to have quality and reliable equipment. The introduction of lean principles can take up to two years, and a planned and structured approach is necessary, as TPM is one of the more complicated lean tools.

Manufacturers throughout the world are faced with the challenge of increasing productivity while keeping humans in the loop in manufacturing industries. This task is becoming even more difficult as robots become increasingly crucial to the manufacturing process by means of emerging technologies, such as brain–machine interfaces and advances in AI. These challenges can be addressed by the next industrial revolution, known as Industry 5.0. In brief, the concept of Industry 5.0 refers to humans and robots working as collaborators rather than competitors [6]. The lean approach to innovation management facilitates the smooth implementation of Industry 5.0 applications. Applying lean principles to product/service development may play a significant role in fostering innovation and long-term organisational learning. It is important to find the right balance between defining norms as guidelines and giving engineers the freedom to pursue unconventional solutions [7].

Lean tools need to be implemented strategically, professionally, and with the right approach for workers to achieve the most benefits from their implementation, especially if a company has not yet introduced similar philosophies. Therefore, a survey was prepared to identify the key factors that obstruct the implementation and success of TPM and lean tools in general. The survey was distributed to several companies that had different numbers of employees and were involved in different areas of production. The aim of the study was to pinpoint key factors that can have negative impacts on the introduction of lean principles and TPM and lead to the failure of their implementation, as well as to provide guidelines on how to avoid such obstacles during the planning, execution, and maintenance of the introduced philosophies.

Literature Review

Expertise and a structured methodology are crucial for the successful introduction and beneficial utilisation of lean and TPM (total productive maintenance) tools in a production plant. Nakajima [8] notes that a number of industries have tried to implement total productive maintenance; however, only a handful achieve an output or utilisation rate of up to 60–90%.

The primary focus of Mandahire's [9] study revolved around achieving a balance between the machines utilised by operators, the operators themselves, and the human resources strategy employed to facilitate this equilibrium. The study revealed that companies aiming to implement TPM to increase profits and productivity should not solely concentrate on their machines or equipment; instead, they must also prioritise their workforce.

Manihalla et al. [10] concluded that the selection and implementation of specific TPM tools are key factors contributing to the success of an implementation program. It is essential to assess the current performance and condition of equipment before initiating the implementation of lean's pillars. They also recognised that TPM's implementation is a continuous process and that it is not possible to achieve returns immediately.

Abhishek et al. [11] identified the key enablers of TPM. In their research, the intensities of the identified enablers were quantified to demonstrate their influence on TPM's implementation. Their findings suggest that it is imperative to ensure the robust implementation of maintenance programmes, such as preventive maintenance, autonomous maintenance, and mobile maintenance, to successfully implement TPM in an organisation.

From an examination of surveys in the literature, Poduval et al. [12] concluded that although there is a substantial body of work dedicated to TPM and the advantages of its implementation, there is a notable lack of emphasis on analyses of the challenges. A common issue observed was that many companies implement TPM at a superficial level, leading to productivity gains that often do not fully realise their maximum potential.

Munir et al. [4] investigated the key factors that can negatively impact the implementation of TPM. There are numerous crucial factors that contribute to its successful implementation. Structured training for TPM coordinators and team members, supported by adequate financial resources, should be provided. Furthermore, it is important to establish a system for measuring both performance and economic benefits as part of the implementation process. The active participation of top management and their ability to effectively communicate with employees at all organisational levels are indispensable prerequisites for the successful implementation of TPM.

Xiang et al. [13] conducted a study in which they proposed a "light" TPM implementation model suitable for small- and medium-sized enterprises. The advantage of their "light" model is that it requires a small sum of capital investment and resources. The model comprises three primary steps:

1. Plan: a preliminary assessment and alignment of the objectives are conducted to begin.
2. Improve: focused maintenance efforts are directed at enhancing the factors that influence equipment OEE (overall equipment effectiveness).
3. Sustain: a sustainability system is implemented to ensure that the improvements made are maintained, preventing a return to the previous state.

They concluded that the use of a systematic and structural approach to the implementation of TPM is key to its success. The model's feasibility was confirmed by its successful implementation within a small- or medium-sized manufacturing enterprise (SME).

Pačaiova et al. [14] presented a comprehensive framework for implementing TPM based on the PDCA (plan–do–check–act) cycle. One unique aspect of the study was its evaluation of how the occupational health and safety (OHS) pillar impacts the stability of the TPM framework. The methodology used involved a detailed analysis of each step in the TPM's implementation, enhanced by the integration of suitable tools to align TPM with ISO 9001:2015 [15]. Their findings shed light on the critical role of management support in the successful implementation of TPM's pillars, including autonomous maintenance. Additionally, the authors highlighted that the often underestimated 5S tool not only plays a fundamental role in TPM but is also significant in the integration of management practices within an organisation.

The primary objective of a study by Chaurey et al. [16] was to delve into TPM's attributes, barriers, and critical success factors (CSFs) within a framework of effective implementation. Notably, the research reveals a deficiency in TPM implementation models tailored specifically for the manufacturing sector. It underscores the absence of large-scale empirical research in this domain. In response, the study calls for the development of a dedicated TPM model suited to manufacturing and identifies key factors gleaned from the existing literature that can facilitate overcoming the challenges in TPM's implementation.

Necas [17] recognised that education plays a crucial role in the successful implementation of a maintenance management process within the TPM framework. Various aspects of education and training within the system were proposed, including the engagement of both internal and external educational and training entities, the selection of suitable venues, and ensuring the availability of necessary technical and material resources.

A study by Manihalla et al. [18] highlighted the critical importance of investing in employee training at various management levels during lean and TPM implementation processes in small- and medium-sized enterprises. Employee training was identified as the most significant factor influencing TPM's implementation in these SMEs. To promote the adoption of TPM strategies and use of their long-term benefits, it is essential to conduct awareness programmes, educational campaigns, and training sessions aimed at motivating the management at SMEs to embrace these practices. These efforts can play a key role in enhancing the overall success of TPM's implementation in SMEs.

From the literature review, it can be concluded that some aspects are recognised as being key for implementing TPM: education, importance of employees, role of management, use of a structural approach, a measurement system, and lean as the basis. On the other hand, some authors agree that there is a notable lack of emphasis on analysing the challenges of implementing TPM; this study fills this research gap. Also, some authors pointed out that there is a lack of a universal model for implementation in industrial enterprises.

2. Materials and Methods

After the literature review, a questionnaire was designed to cover all aspects that can have negative impacts on the implementation of lean tools and TPM. The companies that the survey was sent to range from small to large in size. The responses that indicated a lack of familiarity with the topic were discarded. After checking the credibility of the data, an analysis was performed according to the size of the company as well as the hierarchy of positions within it. A block diagram of the methodology is shown in Figure 1.

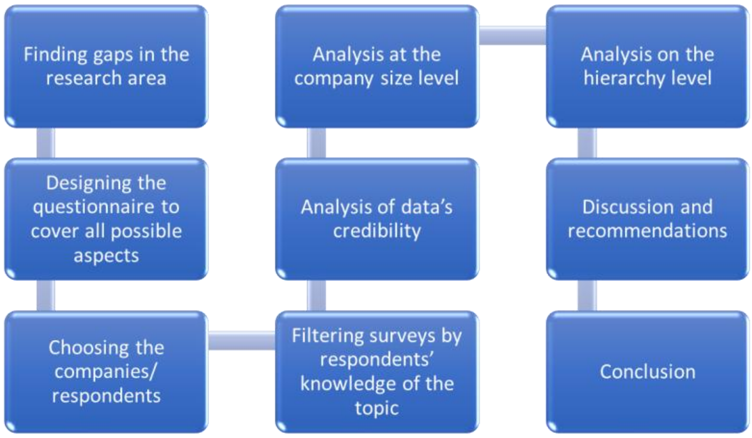


Figure 1. Block diagram of the methodology.

When preparing a survey to collect valuable scientific data, one must keep in mind that there are rules that must be followed for the survey to be credible. To be more beneficial, a survey needs to be prepared following established guidelines. With the development of information and communication technologies and the increasing number of users who successfully apply these technologies in their daily work, web surveys have become the most efficient means of gathering information from a large number of companies. The questions or statements must be clear, the overall time needed to complete the survey must not be too long, and the research must have a clear deadline. The survey must start with a brief introduction explaining why it is being conducted. Lastly, if the survey is also conducted online, a digital format must be considered so that it is accessible to all possible participants [19].

The following steps were performed in the creation of the survey: determination of the research problem, statements, and necessary data, and whether a web survey was suitable for conducting the research; assessment of the possible coverage and sampling issues, concluding whether a web survey could reach the target population; determination of the scales to be used; creation of a draft survey upon which the web survey was to be created; determination of the research schedule; determination of the sample's design; preparation of the messages for the respondents; programming of the web survey and making the necessary changes to the design; pretesting the survey and, if necessary, making corrections; starting the web survey and reaching out to contacts; monitoring the implementation of the research; and closing the survey [20].

The survey consisted of twenty-seven statements grouped into three categories: knowledge of lean tools; introduction of lean tools; and maintenance or sustainability of lean tools. Determining participants' knowledge of lean tools is important to obtaining their level of understanding of the topic. The introduction of lean tools consisted of statements related to their implementation (education, machines, methods, personnel, etc.). Finally, the survey included a set of statements concerning the sustainability of TPM and lean tools to obtain insight into what actions (and their suitability) are taken to preserve the quality of the TPM and lean tools that are introduced. Participants evaluated the statements using a scale from one to five, with one meaning total disagreement and five meaning complete agreement with the given statement. The participants' level of agreement on specific statements determined which aspects have the most influence on the introduction or sustainability of TPM and lean philosophies. The statements used in the survey are provided in Table 1.

Table 1. Survey statements/questions.

Category 1	**Statement No.**	**Knowledge of Lean Tools**
	1	I am familiar with lean systems.
	2	I am familiar with 5S.
	3	I am familiar with TPM.
	4	I am familiar with Kanban.
Category 2	**Statement No.**	**Introduction of Lean Tools**
	5	It was expertly and correctly introduced, and it will be useful.
	6	Sufficient knowledge held by people in charge of its implementation.
	7	Sufficient experience by people in charge of its implementation.
	8	Sufficient support from the director/management.
	9	Organisational structure was adequate for implementation.
	10	Performed within a reasonable timeframe.
	11	I am aware that implementation can be expensive.
	12	TPM performed on suitable equipment.
	13	Education was of sufficient quality.
Category 3	**Statement No.**	**Sustainability of Lean Tools**
	14	Teamwork is satisfactory.
	15	Communication is satisfactory.
	16	Tasks are well aligned with the activities of TPM and lean tools.
	17	There is enough time.
	18	Sufficient qualified persons.
	19	I believe that my job security is not threatened because of lean.
	20	There is no resistance to change.
	21	I consider myself an important part.
	22	Superiors are understanding and patient enough.
	23	TPM and lean tools are considered as essential as other jobs.
	24	Lean activities are not performed only before an audit
	25	An audit is a good use of time.
	26	I believe that the enterprise benefits from TPM and lean tools.
	27	Time spent on lean activities is a good investment.

The statements were formed to cover all aspects that can influence the quality of implementing lean tools. The statements were written by authors with expertise in the field and experience with implementation in actual manufacturing companies. The authors included areas that they think are crucial to establishing lean philosophies. Therefore, the authors divided the questions into three categories. The first category is related to understanding the level of knowledge of the respondents on a given topic. The second category covers the factors concerning preparation, education, team selection, and implementation. The final category focuses on aspects such as the continuation of the performance of tasks, communication, and audits. To obtain different perspectives, the survey asked participants to state which position in the company they occupied so that the data could be examined at the hierarchy level.

As mentioned, the purpose of the survey's first category was to determine respondents' knowledge of the topic. If it was not sufficient, the survey was not used, as the data would not benefit the research. The survey was sent to four different companies. Because of anonymity, the companies are named Company 1, Company 2, Company 3, and Company 4. A total of 36 usable responses were received. Company 1 has 50 employees, and their work focuses on innovative solutions in automation and robot technology. They make automatic lines for various packing and assembly applications, providing custom solutions according to a customer's demands. Lean tools had been in use for 12 months. Some of the tools that they implemented are 5S, Kaizen, and TPM. Company 2 has 150 employees and is in the business of providing engineering solutions. Their employees are mostly engineers who design products, and they have a small manufacturing facility for making prototypes. They had been practicing lean tools for two years. Company 3 has 500 employees, and their area of expertise is the development, design, production, testing, and servicing of power transformers. They started introducing lean tools seven years ago and were among the first big companies in Croatia to implement an extensive lean program. They use 5S, Kaizen, TPM, SMED (single minute exchange of dies), and visual management. Finally, Company 4 is counted as having 800 employees, and they produce semi-finished electromechanical products. They started a lean programme five years prior. They formed a separate department for the introduction of lean tools, and they practice 5S, Kaizen, TPM, SMED, visual management, Six Sigma, and zero waste. All of the companies have experience with a lean philosophy, some less and some more. Answers were received by those in various positions within the companies, ranging from managers, team leaders, and technologists to direct operators in production. Table 2 shows the number of usable responses per company and per worker group type.

Table 2. Number of usable responses per company and per worker group.

Company	Number of Usable Surveys	Worker Group Type	Number of Surveys
Company 1	9	Manager	6
Company 2	13	Leader	10
Company 3	8	Technologist	13
Company 4	6	Operator	7

3. Results

3.1. Analysis of Data

Before presenting the results of a survey, their credibility must be determined, and an analysis of the data themselves needs to be conducted. Thus, an analysis of variance (ANOVA) and Cronbach's alpha were performed on the received answers. ANOVA is one of the most widely used statistical techniques, with applications in areas that include biology, medicine, industry, and finance [21]. The ANOVA test has long been a valuable tool for researchers conducting studies on multiple experimental groups and one or more control groups [22]. The main goal of an ANOVA is to identify whether the null hypothesis is accepted or rejected. A null hypothesis is the proposition that a study's findings will not demonstrate an effect when subjected to a scientific experiment. If the null hypothesis is true, there will be no differences between the intervention and control groups at the end of the study [23]. An ANOVA uses the F-test to statistically evaluate the equality of the means. The F-value is the ratio of the between-group variation and the within-group variation. The given F-value is compared with the critical value of the F ratio derived from the table for a given significance level. The significance level determines the risk of concluding that a difference exists where there is no actual difference. The most common significance level of 0.05 was used. If the given value of F is greater than the F ratio obtained from the tables, we can reject the null hypothesis with a 95% confidence level, as shown in Figure 2.

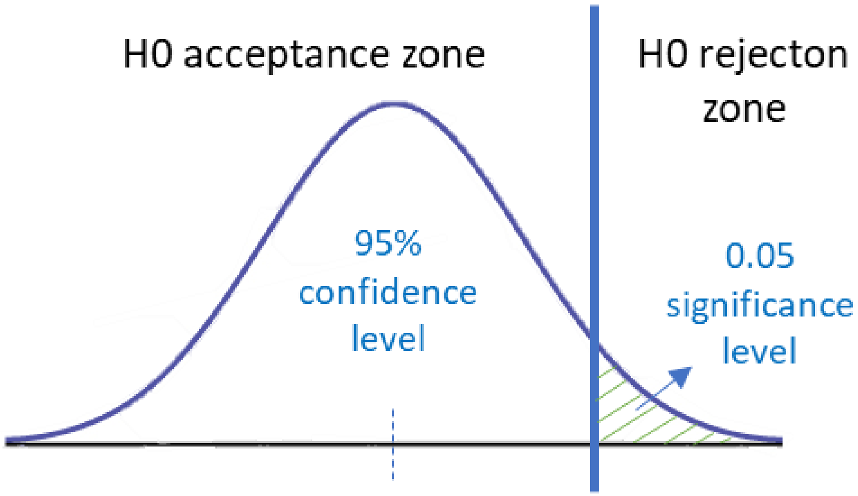


Figure 2. Visualisation of the acceptance or rejection of a null hypothesis.

- F calculated > F ratio at 0.05 significance level: reject the null hypothesis with a 95% confidence level;
- F calculated < F ratio: accept the null hypothesis.

Equation (1) describes how the value of F calculated is obtained:

$$F_{calculated} = \frac{s^2{}_{between\ groups}}{s^2{}_{within\ groups}} \quad (1)$$

where:

$s^2{}_{between\ groups}$ = standard deviation between groups;
$s^2{}_{within\ groups}$ = standard deviation within groups [24].

Equation (2) describes how to calculate the standard deviation:

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1} \quad (2)$$

where:

n = number of variables;
x_i = individual result;
$\overline{x}$ = arithmetic mean of the results of the group;
$n-1$ = degrees of freedom [24].

In this case, n represents the number of questions, x_i represents the answer of one respondent to one of the questions, $\overline{x}$ represents the arithmetic mean of the total number of answers to each question for a specific company, and the degrees of freedom is the number of variables (questions) minus one. After the F-value was calculated for each of the companies in the study, the values obtained were compared with the critical value of F_0 obtained from the table of the critical values for the F distribution for given degrees of freedom. The values were as follows:

1. $F_{calculated\ 1}$ = 2.0837 > $F_{0\ ratio\ 1}$ = 1.4591.
2. $F_{calculated\ 2}$ = 4.1361 > $F_{0\ ratio\ 2}$ = 1.4591.
3. $F_{calculated\ 3}$ = 3.7868 > $F_{0\ ratio\ 3}$ = 1.5543.
4. $F_{calculated\ 4}$ = 5.8746 > $F_{0\ ratio\ 4}$ = 1.4591.

It was concluded that the null hypothesis is rejected, the results of the study are credible, and there is a difference among the populations.

Another approach to the verification of data is to use the Cronbach's alpha (α) and McDonald's omega (ω) coefficients. Cronbach's alpha is the most common estimate of the internal consistency of responses on multi-item bipolar scales [25]. It can be defined as measuring the extent to which item responses (i.e., answers to survey statements) correlate with each other. In other words, Cronbach's alpha estimates the proportion of variance that is systematic or consistent in a set of survey responses. Often, when skew items are present, it is preferable to use the omega coefficient, as it is more robust than the alpha. Therefore, both coefficients were calculated. Equation (3) describes how to calculate Cronbach's alpha:

$$\alpha = \frac{N}{N-1}\left(\frac{\sigma_x^2 - \sum_{i=1}^{N}\sigma_{Yi}^2}{\sigma_x^2}\right) \quad (3)$$

where:

N = number of survey items in the scale;
σ_x^2 = variance of the observed total scores;
σ_{Yi}^2 = variance of item i for person Y [26].

The value of Cronbach's alpha is usually expressed as a number between 0 and 1. A value of 0 means there is no consistency in the measurements. The closer the Cronbach's alpha coefficient is to 1.0, the greater the internal consistency of the items on the scale. An acceptable range is between 0.70 and 0.90, or higher [26].

Omega estimations are based on confirmatory factor analysis (CFA). A CFA model fits the data first, and then the omega is calculated based on the factor loadings and the error variances [27]. Equation (4) describes how to calculate McDonald's omega:

$$\omega = \frac{\left(\sum \lambda_i\right)^2}{\left(\sum \lambda_i\right)^2 + \sum \theta_i} \quad (4)$$

where:

λ_i = factor loadings for item i;
θ_i = error variance of item i [27].

The coefficients were calculated using the freeware software "JASP 0.18.3.0." An analysis was conducted for each individual group of participants (i.e., each company). The results of the analysis are shown in Table 3.

Table 3. Cronbach's alpha and McDonald's omega values for the individual sets of data.

Set of Data	Cronbach's Alpha (α)	McDonald's Omega (ω)
Company 1	0.875	0.882
Company 2	0.865	0.875
Company 3	0.746	0.755
Company 4	0.716	0.720

The cutoff for both coefficients is 0.7. All of the above scores are considered reliable. Because all of the Cronbach's alpha and McDonald's omega coefficients are greater than 0.70, it can be concluded that the data from the surveys are consistent.

3.2. Results

For a better understanding of the given data, the results were grouped both by company and by hierarchical position within the company. This way, it can be observed whether the size of the company and the hierarchical position had any influence on the perception of challenges during the implementation and maintenance of TPM and lean philosophies in general. First, the results were filtered by company. Company 1 is a small enterprise that focuses on innovative solutions in automation and robot technology. Company 2 is a medium-sized company that provides engineering solution services. Companies 3 and 4 are large enterprises with over five hundred employees. The goal was to determine whether the size of an enterprise influenced the perception of potential problems and challenges related to the implementation of lean tools and TPM.

The survey participants were also asked to provide information about their role at the company, so in the second part of the data analysis, the data were grouped according to job function within the company. It is beneficial to see the potential drawbacks from different points of view. As shown in Table 4, the data were grouped into four categories based on roles (i.e., hierarchical levels): operators, technologists, leaders, and managers.

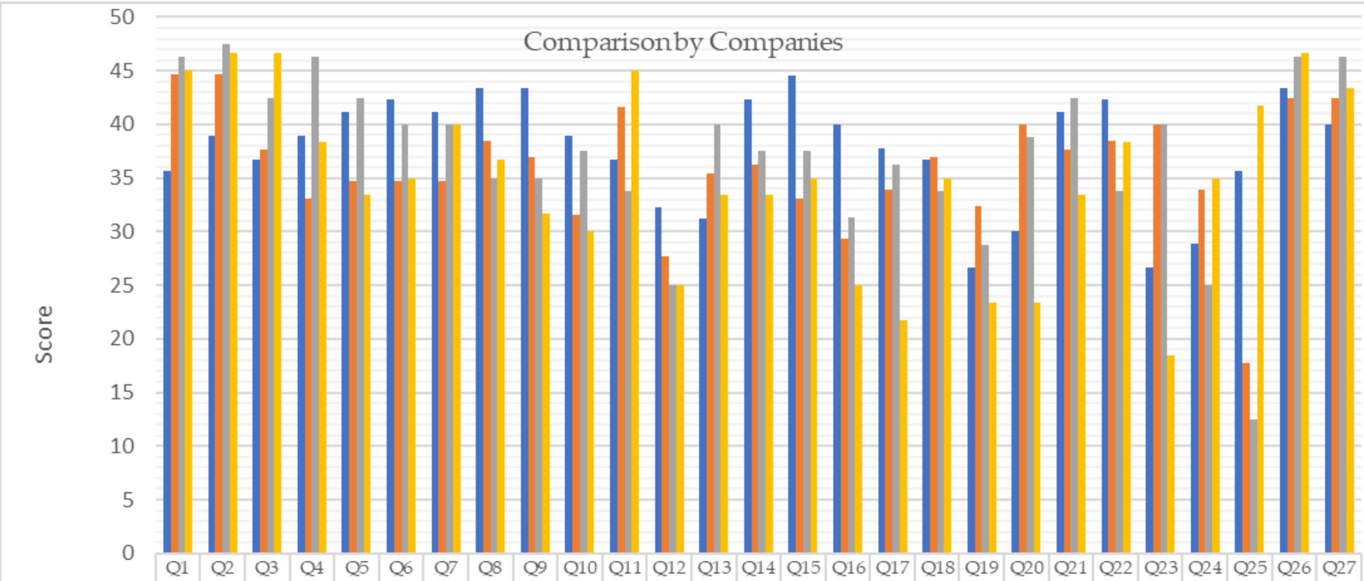
Table 4. Overview of the roles in the companies and the groups in which they were categorised.

Function	Same Group Category
Operators	Operator, worker, manipulator, production employee.
Technologists	Technologist, designer, operating engineer, engineer.
Leaders	Leader, head of department.
Managers	Manager, director, supervisor, executive.

For better results of the data analysis, answers such as operator, worker, manipulator, and production employee were grouped under the "operators" category. Operators' points of view are crucial for understanding the challenges of implementation, because most often it is this level that performs the time-consuming lean tasks, such as data collection, organising, cleaning, and autonomous maintenance. Roles such as technologist, designer, and operating engineer were grouped under "technologists." Individuals in this group are often those who are well educated and among the first to help operators understand the principles. Leaders and heads of departments were all grouped under the hierarchical level of "leaders." They are the decision-makers in a department, often also educated alongside technologists, or they decide who is going to receive the training. Leaders coordinate tasks with the leaders of other departments. Finally, managers, directors, supervisors, and executives were grouped in the "managers" category, which is the highest level of management in an enterprise. They make strategic decisions and are expecting to be briefed on the results of the implementation of lean tools and TPM. They are usually only introduced to the lean philosophy in the form of the vision and goals related to lean tools and TPM.

The numbers below the x-axis (representing statements) are the sums of all of the total answers (each on a scale from one to five) for a selected group. Because a different number of surveys were received from each company, the values were normalised for comparison. The higher the number, the higher the level of agreement with each statement. On the contrary, the lower the number, the lower the level of agreement with a statement. The lowest cumulative answers of the individual groups are emphasised below, and the results are shown in Figure 3.

For Company 1, these were statements Q19 (job security is not threatened by lean), Q23 (lean tools are considered as important as other activities), Q24 (lean activities are not performed only before an audit), and Q20 (there is no resistance to change). Employees at Company 1 (a small enterprise) expressed worry about job safety when performing lean tasks. This can result in poor job performance, the masking of real problems, hiding true results, and conducting lean tasks only before an audit, as recognised by the workers themselves. Management must assure employees that their job is not threatened by lean processes. On the contrary, the aim of lean activities is to ease the workload. The fact that employees at the small company did not recognise the importance of lean tools is a failure of the training program. The employees of Company 1 also thought that there was a certain amount of resistance to change, which is common when implementing new practices but can be reduced using correct implementation methods.



	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27
Company 1	35.6	38.9	36.7	38.9	41.2	42.3	41.2	43.4	43.4	38.9	36.7	32.3	31.2	42.3	44.5	40	37.8	36.7	26.7	30	41.2	42.3	26.7	28.9	35.6	43.4	40
Company 2	44.7	44.7	37.7	33.1	34.7	34.7	34.7	38.5	37	31.6	41.6	27.7	35.4	36.2	33.1	29.3	33.9	37	32.4	40	37.7	38.5	40	33.9	17.7	42.4	42.4
Company 3	46.3	47.5	42.5	46.3	42.5	40	40	35	35	37.5	33.8	25	40	37.5	37.5	31.3	36.3	33.8	28.8	38.8	42.5	33.8	40	25	12.5	46.3	46.3
Company 4	45	46.7	46.7	38.4	33.4	35	40	36.7	31.7	30	45	25	33.4	33.4	35	25	21.7	35	23.4	23.4	33.4	38.4	18.4	35	41.7	46.7	43.4

Figure 3. Results compared by company.

Company 2 is a medium-sized enterprise with approximately 150 employees. Their primary business is the provision of engineering solution services. Employees at Company 2 had the lowest level of agreement concerning statements Q25 (an audit is a good use of time), Q12 (performed on suitable equipment), and Q16 (lean activities are well aligned with other tasks). The employees of this medium-sized enterprise did not recognise audits as an important part of TPM and lean practices in general. It may appear that once a system is established, there is no need for regular reviews and checks. However, auditing any system is crucial for ensuring the stability, continuity, and quality of implemented practices. A common consequence of a lack of audits is that employees tend to become complacent in performing their tasks, inevitably leading to a significant drop in quality. Additionally, employees at Company 2 believed that TPM was not conducted on suitable equipment. This could indicate a lack of strategic selection of equipment suitable for TPM implementation. Typically, a pilot project is developed at the beginning of activities to demonstrate TPM principles with a suitable and compatible system. This approach allows for the philosophy to be understood in an easy and comprehensive way, using suitable equipment as an example. The third major concern raised by employees in the medium-sized company was that the lean activities were not aligned with their regular workloads. This issue can arise in medium- and large-sized enterprises, particularly when multiple trainers and departments are involved. In such cases, it becomes crucial to synchronise activities to ensure alignment among all workers involved.

Employees at Company 3 had the lowest level of agreement with statements Q25 (an audit is a good use of time), Q12 (performed on suitable equipment), Q24 (lean activities are not performed only before an audit), and Q19 (job security is not threatened by lean). As did employees at the medium-sized enterprise, employees of this large-sized enterprise expressed their biggest concerns about lean audits and their benefits. This is another example of why an emphasis on auditing practices during training is vital. Educators must take the time to explain the role of audits in the sustainability of implemented practices. Employees must be included in the audit process so that everybody involved in lean activities is audited at least once and is an auditor themselves. It is important to clarify during training that an audit is not used to "catch" someone not performing planned activities but as a tool to increase the success of established processes. In connection with the questioned importance of the audits, employees of this large-sized enterprise thought that lean and TPM activities were only performed before audits. This is a cause for concern. Lean activities should not be performed for the sole purpose of passing an audit. If this is the case, the leaders of those processes must be reminded and, if needed, retrained. Interestingly, even though employees at Company 3 did not consider lean and TPM activities important, as indicated by the statement that most activities are only done before audits, they still perceived them as threats to their job security if they did not engage in them. This is a failure of implementation, and its effect is the opposite of the intention.

Company 4 is also a large enterprise, with 800 employees. They had the lowest agreement with statements Q23 (lean tools are considered as important as other activities), Q17 (there is enough time), Q19 (job security is not threatened by lean), and Q20 (there is no resistance to change). People at this large-sized company did not see lean tools as important for the company as other everyday tasks and activities. Also, they thought there was not enough time provided for these activities. It is often the case that lean activities are added on top of the daily tasks of workers. In the process of planning implementation, time for additional activities must be included as well. Leaders need to take into account the amount of time needed for these activities and adjust workloads accordingly. Job security was also an issue at this company, and people thought there was great resistance to change. This is often the case at companies with a higher average age and with workers who have been at the company for multiple decades. Some of them have performed their tasks for years in the same way. It is natural to feel resistance to change. It is the responsibility of an educator to thoroughly explain the benefits of lean and TPM practices.

When the results were compiled for all of the companies, the least agreed upon statements were Q19 (job security not threatened by lean), Q23 (lean tools considered as important as other activities), and Q25 (an audit is a good use of time). An overview of the statements with the lowest levels of agreement among the companies is shown in Table 5.

Table 5. Overview of the statements with the lowest levels of agreement.

Company	Lowest Agreement	Second Lowest	Third Lowest
Company 1	Q19, Q23	Q24	Q20
Company 2	Q25	Q12	Q16
Company 3	Q25	Q12, Q24	Q19
Company 4	Q23	Q17	Q19, Q20

Another approach to examining the results is to filter the data according to the job position within a company. This way, different opinions and points of view can be examined with respect to the hierarchical level. Therefore, data were evaluated according to operators, technologists, leaders, and managers. As with the comparison by company, these data were also normalised to compare the results among the groups. The results are visually presented in Figure 4.

Operators indicated less agreement with statements Q19 (job security is not threatened by lean), Q23 (lean tools are as essential as other activities), and Q24 (lean activities are not performed only before an audit). Naturally, operators were most concerned about job safety because it was not within their control. Their performance depends on an evaluation by their leaders and managers. However, when it comes to lean activities and tasks, the operators do not recognise their importance and usually perform them before checks and audits. It is the responsibility of technologists and leaders during training and implementation processes to avoid such outcomes.

Technologists showed less agreement with statements Q19 (job security is not threatened by lean), Q25 (an audit is a good use of time), Q12 (performed on suitable equipment), and Q16 (activities of lean are well aligned with other tasks). The results indicate that technologists share concerns about job security and find audits to not be a valuable use of time. This contradiction is notable because technologists are typically the most knowledgeable about the desired lean tools and philosophies. It is possible that their opinion is linked to the third-lowest agreed-upon statement, suggesting that the implementation of these practices is not conducted on suitable equipment. This may occur if technologists are not responsible for selecting the equipment on which the pilot project is executed. Although it seems obvious, the selection of equipment or part of a production line for the pilot project must always be performed by the personnel that are most educated about the tool that is going to be introduced, and there are examples where this has not been the case.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27
Leader	45	48	43	41	39	41	41	41	36	33	37	29	35	38	35	32	38	37	30	32	40	38	29	26	26	44	43
Manager	42	44	40	32	36	36	40	28	36	26	40	22	30	34	32	28	28	34	36	46	36	38	48	38	14	46	46
Operater	35	37.5	35	35	42.5	42.5	42.5	37.5	42.5	40	35	35	30	42.5	45	40	30	30	25	27.5	35	40	25	27.5	37.5	40	30
Technologyst	43.9	45.4	40.8	40	36.2	33.9	35.4	40.8	37	36.2	42.4	26.2	37.7	37.7	40	30	32.4	36.2	25.4	31.6	40.8	38.5	33.1	34.7	25.4	46.2	46.2

Figure 4. Results of the survey grouped according to position within the company.

Leaders showed less agreement with statements Q24 (lean activities are not performed only before an audit), Q25 (an audit is a good use of time), Q12 (performed on suitable equipment), and Q23 (lean tools are as essential as other activities). It is concerning that the leaders also recognise that lean activities are performed more actively, mostly before audits. Because internal audits are friendly, meaning their purpose is to sustain good practices, they are always announced. Therefore, it would be beneficial to perform unannounced internal audits. It would provide a better picture of the status of a lean tool's performance. Another concern of the leaders was that an audit itself was not a good use of time. Often, lean is imposed on leaders by management, which expects results. Because leaders are not often the ones performing the tasks, it is easy for them to underestimate these activities, as recognised in the survey.

Managers showed lower levels of agreement with the statements Q25 (an audit is a good use of time), Q12 (performed on suitable equipment), and Q10 (implementation of lean tools was performed within a reasonable amount of time). For executives, the results of their investment, rate of savings, and return on investment time are usually the most important. High-level management often only understands the philosophy superficially, just enough to decide whether to invest. Management also thought that time spent on audits was not so useful and, in their opinion, it was not performed on suitable equipment. It is interesting to note that their third-lowest level of agreement was on the statement related to lean and TPM tools being implemented within a reasonable time frame. Often, the implementation of lean tools can take up to two years (depending on the size of the enterprise, the number of personnel involved, the scope of the implementation, and the number of lean tools being implemented). So, management, in this case, showed concern about the time span of the implementation. Therefore, when planning the introduction of lean tools, it is crucial to prepare and present a period, timeline, or Gantt chart to investors. Establishing clear milestones and time-bound goals is essential for maintaining a transparent dashboard to monitor activities. This approach helps prevent issues related to execution deadlines for specific activities or the entire project. Table 6 provides an overview of the statements with the lowest level of agreement according to job position within a company.

Table 6. Overview of statements with the lowest level of agreement.

Job Position	Lowest Agreement	Second Lowest	Third Lowest
Operators	Q19, Q23	Q20, Q24	Q13, Q17, Q18, Q27
Technologists	Q19, Q25	Q12	Q16
Leaders	Q24, Q25	Q12, Q23	Q19
Managers	Q25	Q12	Q10

4. Discussion

There are many factors that can negatively impact the introduction and sustainability of TPM and other lean tools. However, only a few of the most critical are emphasised here based on the answers provided. The least agreed-upon statement regarded audits as a good use of time. An internal audit is defined as an activity designed to add value and improve an organisation's operations [28]. Another definition of lean auditing is that it is an approach to managing an auditing process and organisation (one that provides auditing services) that supports the concept of ongoing improvement, a long-term approach to work aimed at systematically achieving changes and improving audit quality, including efficiency, effectiveness, and transparency [29].

Although an audit is a key tool for maintaining the quality of lean tools and ensuring the sustainability of implemented philosophies, employees at all levels failed to see this. Audits, which ensure a constant level of quality in the lean philosophy, are as important as all of the previous steps in its implementation. It is important to clarify during the training phase why an audit is being held and to ensure that all levels of the hierarchy participate in its preparation and performance such that everybody involved in lean activities is, at least once, an auditor themselves or is being audited. Because many answers in this study indicated that lean and TPM activities were conducted only before an audit, it may be beneficial to conduct some unannounced audits. For a successful internal audit, it is important to have a supportive control environment, as the authors of [30] showed a statistically significant positive correlation between the perceived usefulness of an internal audit and a higher level of a supportive control environment. Under these conditions, therefore, the managers and audit committee see internal audits as more effective, and the perceived usefulness expected from an internal audit is higher. For an audit to be conducted successfully, established steps need to be followed. Dobrowolski, Sulkowski, and Adamisin [29] developed a set of instructions: specify the audit value and identify the value stream, flow, pull, and perfection.

Another aspect upon which employees did not agree is that TPM was performed on suitable equipment. At all levels, there was uncertainty about whether the optimisation was conducted on the right set of machines. It is important to choose production equipment and infrastructure in accordance with the demands of the lean production system. When selecting the first pieces of equipment to showcase lean, it is important to analyse whether the equipment is easy to operate and maintain. In addition, factors such as error proofing, reliable maintenance, the safety of the operators, and support should be considered [31]. One way to start is by developing a pilot project using the piece of equipment or machine that is most compatible with TPM optimisation. In this way, employees can clearly see the benefits of TPM and lean activities, especially if they are just being introduced to these philosophies, which they can later apply to the more complicated machines. The fact that the study shows that there were significant concerns about whether the right equipment was selected for TPM's implementation can indicate a lack of strategic selection of suitable equipment. This may occur if technologists are not responsible for selecting the equipment on which the pilot project is executed. Although it seems obvious, the selection of equipment or part of a production line for the pilot project must always be performed by the personnel who are the most educated about the tool being introduced, and there are examples where this is not always the case.

Job security was recognised as the next key factor that can negatively impact the introduction and sustainability of lean activities. Participants mostly expressed their concern that if they did not participate in lean activities, their jobs could be endangered. This can lead to routine work of low quality, or it can lead to a state in which workers do the bare minimum just to get by. Lean can also have an impact on fears concerning its transformation of the workplace and effects on employment [32]. Maslow's Hierarchy of Needs groups basic human needs into a hierarchy. They are physiological (i.e., food and clothing), safety (i.e., job security), love and belonging needs (i.e., friendship), esteem, and self-actualization [33]. It is no wonder that one of the biggest concerns of the employees was job security, as this is, according to Maslow, the second human need in the hierarchy. Therefore, it is important that employees are not threatened in this way by lean tools. Educators must find a way to motivate employees to use lean tools that are not based on fear but on their own benefit. Educators can study McClelland's needs and theory of motivation model, which attempts to explain how the needs for achievement, power (authority), and affiliation affect people's actions in a management context [34]. Motivators are intrinsic factors that increase employees' job satisfaction, whereas hygiene factors are extrinsic factors for the prevention of employees' dissatisfaction [35].

Another aspect that should be highlighted is the feeling by employees that lean activities are not as important as other work tasks. That is often the case in companies with a higher average age and with workers who have been at the company for multiple decades. Some have performed their tasks for years in the same way. It is natural to feel resistance to change. Lean activities should not be considered separate jobs but rather integrated systems of existing tasks with the aim of optimising material and information flow, but leaders need to take into account the amount of time needed for these activities and adjust the workload accordingly.

On the other hand, the most positive answers were provided for the statements that the enterprise will benefit from using lean tools and that time spent on performing lean activities in production is a good investment. This shows that although employees may have some doubts, they recognise that, in the end, it will be beneficial for the enterprise in the long run. The survey also showed that one of the most recognised lean tools is 5S. It can be a good starting point for the introduction of lean in general because it is a simple and cost-effective method for the organisation, optimisation, and standardisation of the workplace.

When data were analysed at the company size level, it was evident that workers at the small enterprise were concerned about job security while performing lean tasks. This apprehension may lead to suboptimal job performance, obscuring actual issues, concealing true outcomes, and conducting lean tasks shortly before audits, as acknowledged by the employees themselves. The employees of the medium-sized enterprise did not recognise audits as an important part of TPM and lean practices in general. It might appear that once a system is established, there is no need for regular reviews and checks. However, auditing any system is crucial to ensuring the stability, continuity, and quality of implemented practices. A common consequence of lacking audits is that employees tend to become complacent in performing their tasks, inevitably leading to a significant drop in quality. Additionally, employees at Company 2 believed that TPM was not conducted on suitable equipment. This could indicate a lack of strategic selection of equipment suitable for TPM implementation. Like the employees at the medium-sized enterprise, the employees at the large-sized enterprises also expressed that their biggest concerns were related to lean audits and their benefits. This serves as another example of why the emphasis on auditing practices during training is vital. Educators must take the time to explain the role of audits in the sustainability of implemented practices. Individuals at the other large-sized company did not perceive lean tools as crucial for the company compared with other routine tasks and activities. Additionally, they believed that insufficient time was allocated for these activities. It is a common occurrence for lean activities to be perceived as an additional burden on top of the daily responsibilities of workers. During the planning phase of implementation, adequate time for these supplementary activities must be factored in.

The data were also observed at the level of position within a company. Operators often failed to recognise the significance of lean and TPM tasks, and they typically executed these tasks just before checks and audits. It is the responsibility of technologists and leaders to prevent this by emphasising the importance of these tasks during the education and implementation processes. Technologists expressed concerns about job security and perceived audits as not being a valuable use of time. The latter is significant, as technologists usually possess the most knowledge about the desired lean tools and philosophies. It is possible that their viewpoint is correlated with their third-lowest agreed-upon aspect, indicating that the implementation of these practices is not conducted on suitable equipment. This situation may arise if technologists are not involved in selecting the equipment for the pilot project's execution. Leaders recognised that lean activities were performed more actively, mostly before audits. Often, lean is imposed on leaders by the management, which expects results. Because leaders are often not the ones performing the tasks, it is easy for them to underestimate these activities, as recognised in the survey. Management did not find the time spent on audits to be particularly useful or that lean and TPM tools were implemented within a reasonable period of time. Implementing lean tools can often extend up to two years, depending on the enterprise's size, the number of personnel involved, the scope of implementation, and the number of lean tools to be implemented. Therefore, management in this case expressed concern about the implementation's time span. Establishing clear milestones and time-bound goals is essential for maintaining a transparent dashboard to monitor activities.

It was recognised that the Industry 4.0 (I4.0) paradigm can help reduce the negative impact of some of the aspects mentioned in the study. I4.0 refers to the fourth industrial revolution, characterised by the integration of digital technologies, automation, and data exchange into manufacturing processes. It involves the use of technologies like the Internet of Things (IoT), artificial intelligence, and big data to create "smart factories" for more efficient and interconnected industrial production. There is a positive correlation between lean automation (LA) and operational performance within an Industry 4.0 environment. The integration of LA technologies positively impacts productivity, delivery, inventory management, and quality—all crucial performance indicators [36]. The authors of the study [37] emphasised the transformative effect of I4.0 on production dynamics, replacing conventional forecast-based planning with real-time planning and dynamic self-optimization. The study notes the importance of IoT devices in collecting data for predictive maintenance and underscores the empowering effect of Digital Twins (DT) on TPM. A study [38] suggests that VR, as part of I4.0, can serve as a substitute for physical boards in guiding operators and training them for maintenance objectives. This has the potential to enhance educational and training outcomes. The core concept in the study [39] centres on the introduction of network-linked intelligent systems within I4.0, aiming to achieve self-regulating production processes. The authors of [40] emphasise the role of data science in I4.0, transforming real-time data into meaningful knowledge. This includes activities such as collecting, checking, transforming, and restructuring data, highlighting the significance of data-driven decision-making.

The transparency of data and its ready availability are key benefits offered by Industry 4.0. The ease of accessing real-time data through integrated systems reduces the laborious task of manually filling out forms for overall equipment efficiency (OEE) calculations, which can raise employee motivation and satisfaction. This streamlined data availability makes decision-making more accurate and timely. The simulation capabilities of Industry 4.0 play a pivotal role in gaining insights into suitable equipment selection for TPM implementation. By employing simulations, manufacturers can assess the compatibility of equipment with lean philosophies, contributing to informed decision-making in the implementation process. IoT, an integral component of Industry 4.0, enables the retrieval of real-time data crucial for monitoring equipment performance. This real-time data are essential for ensuring the continuous improvement of equipment efficiency and aligning with TPM principles. The integrated functions, simulations, and real-time data collection within Industry 4.0 positively impact employee satisfaction. Eliminating the need for manual data collection enhances the efficiency of work processes, contributing to a more satisfying and productive work environment. The integration of Industry 4.0 technologies offers promising solutions to the challenges identified in lean manufacturing. From enhancing operational performance through automation to real-time planning, virtual reality applications, self-regulating production, and leveraging data science, these technologies pave the way for a more efficient and adaptive manufacturing landscape. Adopting Industry 4.0 principles can contribute to overcoming obstacles and ensuring the successful implementation and sustainability of lean tools and TPM practices.

Every factor identified by this research should be carefully considered before the implementation of TPM tools, and appropriate actions must be taken to prevent potential drawbacks in the introduction or sustainability of implemented practices.

5. Conclusions

The aim of this study was to recognise key factors that can negatively impact the introduction and sustainability of TPM and lean tools in general. To achieve this, a survey was developed that consisted of twenty-seven statements divided into three main categories: knowledge of lean tools, implementation process of lean tools, and sustainability of lean tools. The survey was conducted with four companies, ranging from fifty employees to eight hundred employees. Employees could agree or disagree with the statement using a scale ranging from one to five, with one meaning they did not agree and five meaning they fully agreed with the individual statement. For the provided answers, an analysis of variance and Cronbach's alpha were performed to ensure the data obtained were credible. Answers were analysed by individual group (i.e., company) and by position in the company's hierarchy (i.e., operators, technologists, leaders, and managers). For better data analysis results, functions such as operator, worker, manipulator, and production employee were all grouped under the operators category; technologist, designer, and operating engineer were grouped under technologists; leaders and heads of departments were grouped under the leaders hierarchical level; and, finally, managers, directors, supervisors, and executives were grouped in the managers category.

After the analysis of the answers, four key factors were recognised that could negatively impact TPM and lean tools in general. These are a lack of recognition of the benefits of an internal audit, equipment selection, job security, and not giving enough attention to lean tasks (compared with other job activities). Recommendations were provided on how to reduce the impact of these factors and prevent their negative influence. On the other hand, some positive aspects were also recognised. Employees at all levels expressed the belief that the enterprise would, in the end, benefit from the implementation of lean tools and that the time invested in them was time well spent. This shows that employees recognised the benefits, and if the training and implementation were conducted strategically in a structured and careful manner, there was enough will to perform the tasks. Also, because successful implementation depends on the support of management, it is positive that those in management positions also recognise the benefits that lean may have for optimisation. To achieve this, while planning the introduction of lean tools, it is important to prepare and present a timeframe, timeline, or Gantt chart to managers or investors. Establishing clear milestones and time-bound goals is essential for maintaining a transparent dashboard to monitor activities. This approach helps prevent issues related to execution deadlines for specific activities or the entire project.

I4.0 addresses challenges in lean manufacturing by integrating technologies such as IoT, AI, and big data. LA within I4.0 correlates positively with operational performance, impacting productivity, delivery, inventory, and quality. Studies emphasise I4.0′s transformative effects on planning, maintenance, and employee training. Intelligent systems in I4.0 aim for self-regulating production, while data science transforms real-time data into meaningful knowledge. The transparency and availability of data offered by I4.0 streamline OEE calculations, reduce manual tasks, and boost employee satisfaction. Simulation capabilities aid in equipment selection for TPM, ensuring compatibility with lean philosophies. Adopting the principles of Industry 4.0 shows potential for overcoming challenges and ensuring the effective implementation and long-term success of lean tools and TPM practices.

However, this study is only applicable to manufacturing enterprises. Also, only responses from participants with prior knowledge of the topic were included. This criterion was applied to ensure that the collected data reflected a level of familiarity with the subject matter, enhancing the relevance of the study's findings.

For future research, there is the possibility of examining in depth all of the factors mentioned that can have negative impacts and defining a strategic model for the implementation of TPM and other lean tools that is universally applicable to manufacturing enterprises of all sizes. The provision of education and the use of a strategic approach are key to the fully successful implementation of TPM and sustainable lean tools.

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