encyclopedia

MDPI

Entry

Implementation and Improvement of the Total Productive Maintenance Concept in an Organization

Marta Wolska [1,*], Tadeusz Gorewoda [2,*], Marek Roszak [3] and Lesław Gajda [4]

[1] Centre of Analytical Chemistry, Łukasiewicz Research Network—Institute of Non-Ferrous Metals, ul. Sowińskiego 5, 44-100 Gliwice, Poland
[2] Centre of Metallurgy, Łukasiewicz Research Network—Institute of Non-Ferrous Metals, ul. Sowińskiego 5, 44-100 Gliwice, Poland
[3] Department of Engineering Materials and Biomaterials, Faculty of Mechnical Engineering, Silesian University of Technology, ul. Konarskiego 18A, 44-100 Gliwice, Poland; marek.roszak@polsl.pl
[4] Department of Materials Technology, Faculty of Materials Engineering, Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice, Poland; leslaw.gajda@polsl.pl
* Correspondence: marta.wolska@imn.lukasiewicz.gov.pl (M.W.); tadeusz.gorewoda@imn.lukasiewicz.gov.pl (T.G.)

Definition: Total Productive Maintenance (TPM) is an infrastructure-managing methodology that leads to improvements in production efficiency, quality, and safety. It includes a set of processes, techniques, and strategies based on forecasting, maintenance, the optimized cooperation of different company departments, and the minimization of costs related to downtime or accidents caused by equipment failure. This article discusses the history, assumptions of the TPM concept, and approach to implementing Total Productive Maintenance in organizations in detail. The right ingredients required for successful TPM implementation and barriers to implementation are also reviewed. The benefits of implementing TPM in organizations are presented and supported with examples of implementations in production and non-production organizations. The article is addressed to representatives of the manufacturing industry. TPM also indicates a high potential for implementation in non-production areas, which may be interesting, for example, for the service, medical, or laboratory industries.

Keywords: Total Productive Maintenance; organization; maintenance; TPM implementation

Citation: Wolska, M.; Gorewoda, T.; Roszak, M.; Gajda, L. Implementation and Improvement of the Total Productive Maintenance Concept in an Organization. *Encyclopedia* **2023**, *3*, 1537–1564. https://doi.org/10.3390/encyclopedia3040110

Academic Editors: Raffaele Barretta and Massimiliano Lo Faro

Received: 30 October 2023
Revised: 29 November 2023
Accepted: 14 December 2023
Published: 18 December 2023

1. Introduction

The processes of globalization and the integration of individual markets, as well as the dynamic development of the economy, are particularly challenging for organizations. At the turn of the 20th and 21st centuries, a global tendency could be observed which included replacing mass production with product individualization, economies of scale with field economies, competition on price with competition on quality, and specialized trained employees with employees with comprehensive skills [1]. The increase in competition in domestic and international markets means that organizations face the difficult challenge of formulating competitive strategies that will provide them with a relatively sustainable advantage that determines business continuity [2]. Additionally, the growing competitive threat from more innovative investors promoting flexibility, diversity, and creativity in action forces the effective and efficient implementation of changes in approaches to management, manufacturing technologies, and the speed of implementing changes in relation to customer expectations or supplier attitudes. Under the conditions of the intensive development of information technologies and process automation, the transformation of organizations operating locally into global organizations is possible in a relatively short period of time, often without the need to incur huge financial outlays. This situation forces a broader look at the concept of achieving competitive advantage, one of the foundations of which is the innovative attitude of the organization, understood as openness to the implementation of new information technologies, management systems, concepts of infrastructure, and human resources management, as well as the automation of the processes themselves and their far-reaching optimization [3]. Over the years, the nature of production has changed dynamically, as a result as did the implementation of advanced manufacturing and manufacturing technologies, but the benefits of the implemented changes were often limited due to unreliable or inflexible machine park [4].

Currently, organizations, especially manufacturing ones who want to create their business effectively, must have appropriate equipment and maintain it in a good technical condition. Any negligence in maintenance practices directly reduces the efficiency and reliability of the equipment, leading to rapid deterioration and reduced availability of the equipment due to excessive downtime. As a result, the quality of production is reduced and the amount of inventory increases, which ultimately leads to unreliable deliveries affecting the efficiency of supply chains [5]. In practice, the reliability of machine park contributes to the efficiency and profitability of production systems [6]. Organizational managers show great interest in implementing control methods consistent with the Lean Manufacturing concept. The techniques and methods included in this approach allow for the systematic identification and elimination of losses related to machinery by implementing appropriate solutions. The correct implementation of Lean tools makes it possible to increase the scale of production while reducing the use of the machine, time, space, and human effort. As manufacturing operations become increasingly complex, Total Productive Maintenance (TPM), which is associated with the Lean philosophy, is becoming the go-to solution for ensuring efficient, cost-effective, high-quality production [7].

2. Maintenance Process Issues and Concepts

Asset and equipment needs have changed over time, putting on pressure in the scope of supervision over the maintenance of operational machines to proactively adapt machines' availability to meet the organization's rapidly changing process requirements. Consequently, infrastructure management has undergone significant changes in recent years. In the current managing organizational model, the maintenance function has become an integral part; maintenance, as a supporting function in enterprises, plays an important role in business and operational strategies such as Lean Maintenance, Just-In-Time production, and Six-Sigma.

Currently, machine and equipment maintenance is an indispensable element of the functioning of production and non-production organizations [8,9]. The main goals are to keep machines and equipment operational and to reduce undesirable, accidental, and unexpected downtime and replace it with planned downtime—so-called preventive maintenance. Correct maintenance management in the organization results in the minimization of operating costs, a general decrease in the number of failures, and the elimination of waste. Strategic investments in the maintenance process can lead to improved efficiency and increased process potential [10,11]. For maintenance to make a real contribution to organizational profits, productivity, and quality, it must be considered an integral part of the adopted business strategy [12]. This priority should include all levels of management in the organization to develop awareness among employees that the maintenance process can have a direct impact on the success or failure of the organization's goals [13]. The effective integration of maintenance processes with the engineering function or other processes in the organization is responsible for controlling the costs of work, materials, tools, time, and overhead costs [14,15]. Strategic investments in the maintenance process can lead to the improved efficiency of an organization's processes and strengthen its competitive market position [12]. Maintenance strategies traditionally fall into three categories, each with their own goals and related benefits (see Table 1 and Figure 1).

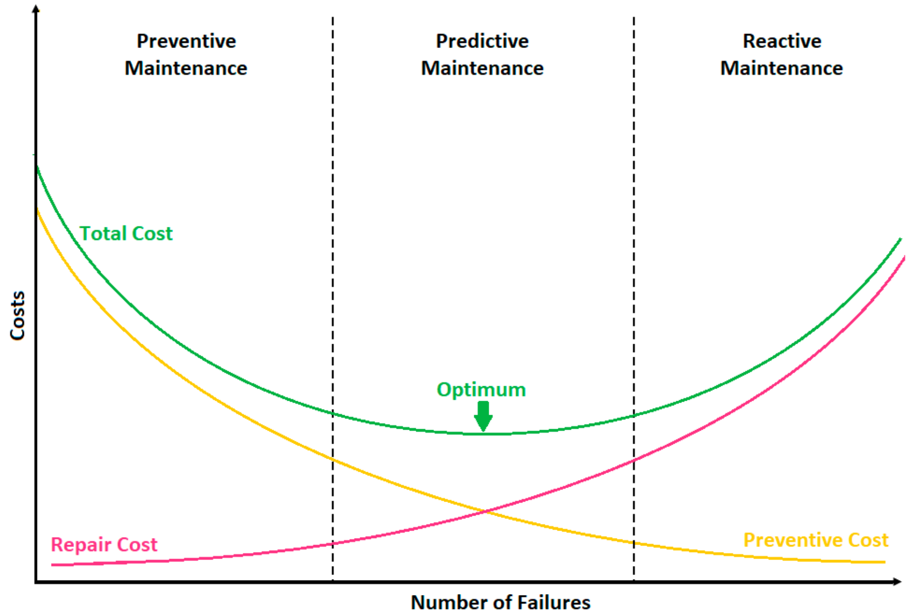

Figure 1. Relation between cost and number of failures for different types of maintenance. Data from [21].

Table 1. Correlation type of maintenance [16–20].

Goals and Related Benefits	Reactive Maintenance	Preventive Maintenance	Predictive Maintenance
Inspection	Visual inspection	Instrumental inspection	Sensor monitoring
Timing	After breakdowns	At predefined intervals	When required
Characterization	Fix on failure Low-priority equipment Can lead to runaway maintenance costs and overburden	Schedule-driven "standard" approach PM creek can occur Not dynamic to changing circumstances	Condition-based Timely and informed monitoring Data-driven Requires data and resources to implement
Useful	For low-criticality equipment or late-life assets	Standard in the operational phase of an asset, but requires optimization	Selective—can be used on high-criticality equipment once PM history is adequate
Benefits	Maximum utilization and production value from asset	Lower maintenance costs Less equipment malfunction and unplanned downtime	Connected technologies provide a holistic view of asset health Improved analytics options Removes the necessity to run-to-failure or replace a part while it still has life
Challenges	Unplanned downtime Potential for further damage to the asset Higher maintenance costs	Need for spare part and inventory management Increased planned downtime Maintenance on seemingly perfect assets	Increased upfront infrastructure setup (sensors, systems, etc.) Complex system-implementation requirements including data-management technology and user adoption

The approaches to maintenance are varied, and the organization chooses the most advantageous method of carrying out operational services depending on its needs or technical and economic possibilities. The literature shows the following division [11,20,22]:

1. No operational maintenance: operation until the old device is replaced, overhauled, or a failure occurs and it needs to be removed.
2. Carrying out preventive maintenance in one of the following forms:

a. Periodic: carried out at specific fixed intervals;
b. Resource-based: implemented after the device has completed a certain amount of work;
c. If possible: performed when certain organizational and economic conditions are met, e.g., access to the device is ensured due to a periodic break in work;
d. Condition-dependent: the moment of service is determined on the basis of periodic inspections of the condition of the device or its elements particularly exposed to wear.

3. Conducting predictive maintenance (predictive maintenance)—predicting and preventing failures based on reports of previously performed repairs and statistical analysis of the probability of failure reoccurrence. This analysis determines possible moments of failure and provides the information necessary for the proper management of spare parts.

3. Characteristics of the Total Productive Maintenance Concept

Total productive maintenance (TPM) was created based on the above-mentioned concepts of equipment maintenance. As the name suggests, it consists of three words, as follows [23]:

- Total: means consideration of every aspect and involvement of all employees.
- Productive: emphasis on performing activities during production, minimizing production problems.
- Maintenance: independent maintenance of equipment by production operators.

There are many definitions of TPM in the literature [1,12,24–29], and each emphasizes the need to optimize equipment efficiency through effective management and teamwork. It should be noted that these definitions suggest that TPM should be characterized as an element of the organization's management strategy, providing the opportunity to optimize activities undertaken in the field of supervision over the maintenance of machines and devices with the participation and involvement of all employees, and aimed at improving the efficiency of implemented processes and improving the quality of the implemented processes and manufactured products.

3.1. History of TPM Concept

The history of the TPM concept dates back to the 1950s in Japan. In 1954, a group was formed that focused on studying existing preventive maintenance (PM) programs. In 1961, the Japan Management Association (JMA) established the UR Plant Maintenance Committee (PMC), chaired by Seichii Nakajima. In 1962, the PMC translated a set of weapons-maintenance manuals, issued by the US Navy, from English into Japanese. As a result of the research work, in 1963, a publication was published in which great emphasis was placed on explaining what PM is and its impact on the functioning of an enterprise. In 1964, a team was established consisting of PMC representatives and representatives of machinery and equipment manufacturers. This team worked on developing appropriate preventive programs for individual sets of machines and devices. In the same year, a consolidated team—the Japan Institute of Plant Engineers (JIPE)—established an award for companies that properly implement a preventive maintenance program called the Award for PM Excellence. The first winner of the award was Nippondenso from the Toyota group [30,31].

The initial operating concept implemented in Nippondenso was based on the division of roles between employees: operators produced goods using machines, and the maintenance group was responsible for maintaining these machines. With the automation of processes, the model used became problematic due to too few employees being responsible for maintenance. Management decided that routine equipment maintenance would be performed by operators, which formed the basis for autonomous maintenance. The maintenance group performed only necessary maintenance work. Machines and equipment modifications were also made to improve reliability. Thus, preventive maintenance, along with preventing maintenance and improving maintenance efficiency, gave rise to productive maintenance. The aim of productive maintenance was to maximize the efficiency of machines and equipment in order to achieve optimal life cycle costs of production equipment. Nippondenso created quality circles in which employees participated for PM purposes. Thus, all employees participated in the implementation of the PM program. Based on these achievements, Nippondenso received an award for the development and implementation of the concept of PM [32].

Over the last 40 years, only 20 organizations worldwide have received the highest award—the TPM World Class Award—for implementing the TPM concept. Since its inception, the TPM Excellence Award has been awarded to approximately 2000 plants [33].

Over the years, the Japan Institute of Plant Maintenance (JIPM), formerly JIPE, has published a number of studies on the subject of the technical maintenance of individual machines and devices. In 1971, JIPM changed the nomenclature from PM to TPM, which was originally translated as Total Member Participation Productive Maintenance, and defined TPM, focusing mainly on the production sector [34]:

- TPM aims to maximize equipment performance (improve overall performance);
- TPM aims to create a comprehensive PM system, designed for the entire life of the equipment;
- TPM works in all equipment sectors, including planning, operation, and maintenance;
- TPM is based on the participation of all members, from top management to front-line employees;
- TPM implements PM through motivation management.

In 2016, such comprehensive maintenance was officially recognized by the IATF (International Automotive Task Force) and included the standard for the automotive industry, IATF 16949:2016, as a formal requirement in the latest version of the main quality-management system [32,35]. The previous edition of the standard only addressed preventive and predictive maintenance. The current version also forces us to focus on improving key metrics and performing cyclical renovations based on fixed, adopted time intervals.

3.2. Main Foundations of the TPM Concept

Since its creation, the concept has undergone far-reaching evolution. Currently, TPM is indicated as a very important Lean Manufacturing tool. TPM is a solution that allows you to use machines and devices in organizations in the most effective way. TPM, unlike the assumptions regarding traditional maintenance, assumes the primary role of broadly understood prevention over the production plan; the time spent on inspections, modifications, and maintenance pays off in the later period when the machine works without unexpected interruptions and the product quality is repeatable and appropriate for requirements [36].

TPM goals are implemented in two areas: man and machine. An important feature of TPM is the introduction of the autonomous maintenance of devices and machines by operators, i.e., the integration of many basic maintenance activities with the production process [37]. The task of TPM is to increase employee effectiveness by expanding their skills and knowledge, thus increasing their responsibility. Employees become more engaged in their work, can properly interpret situations, and, thus, make the right decisions on their own. A key element is the participation of equipment operators in the improvement program and in the prediction and prevention of failures. Close cooperation between maintenance workers and operators during the maintenance and repair of devices allows for an increase in the competence of both parties in terms of the knowledge of all aspects related to maintaining the faultlessness of equipment [38].

TPM meets the view that only the purchase of new machines will translate into the improved efficiency of the entire production process. In practice, purchasing new machines always involves large investment expenses that many organizations cannot afford [39]. According to TPM, a new machine does not mean an immediate improvement in efficiency. New machines equipped with the latest diagnostic solutions, without a well-designed and implemented maintenance plan and a well-trained crew, will not achieve their planned maximum efficiency of use (Figure 2).

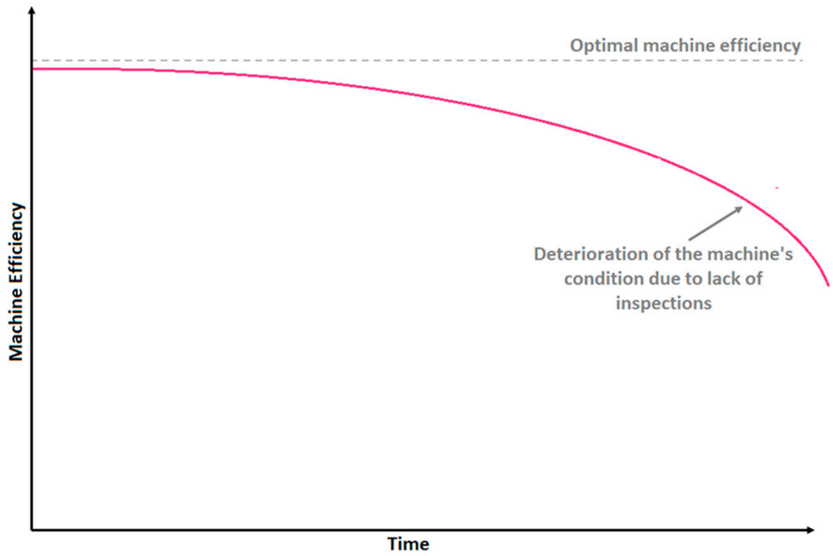

Figure 2. Decrease in the efficiency of machine use without a properly prepared machine-inspection system [38,39]. Reprinted with permission from Ref. [39]. Copyright 2015 Leantrix.

The situation is completely different when implementing solutions that improve the work organization of the existing machinery. Achieving the maximum possible efficiency is possible thanks to a well-developed maintenance plan and appropriate operator training (Figure 3) [38,39].

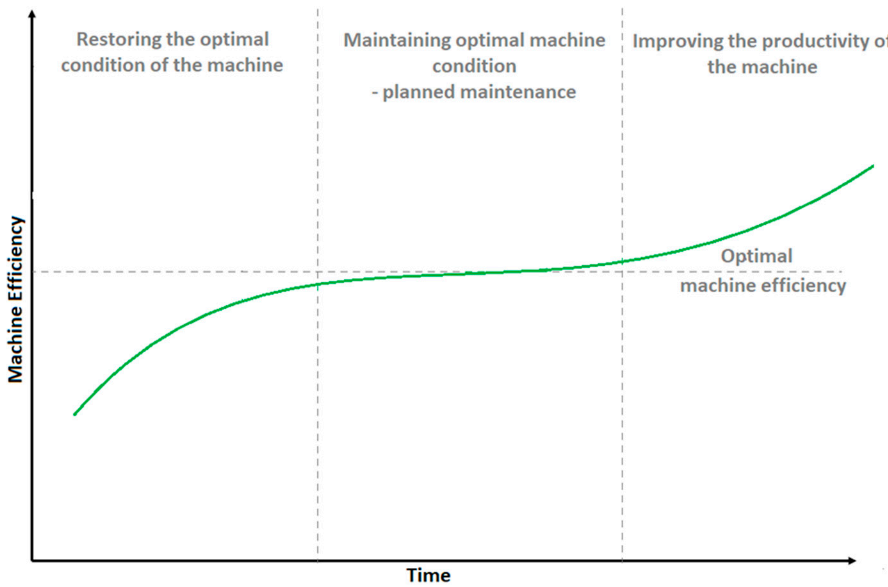

Figure 3. Improving the effectiveness of machine use with a properly implemented system of planned inspections and improvement activities [38,39]. Reprinted with permission from Ref. [39]. Copyright 2015 Leantrix.

Therefore, it is crucial to increase the efficiency of machine use by improving the work organization through designing and observing maintenance standards, implementing an effective employee training system, and a work improvement process [9]. The number of benefits it brings means that this system is increasingly being used in many companies conducting both production and non-production activities. The TPM method is based on predicting and preventing faults during equipment operation, which makes it possible to extend repair cycles, reduce the number of malfunctions and failures, and minimize the time of their removal, as well as better spare-parts management [37]. The most important goals that organizations implementing TPM want to achieve are increasing the stability of production processes, extending the period of operation, reducing the maintenance costs of machines and devices, reducing or eliminating waste, producing a low batch quantity at the earliest possible time, achieving a high level of quality, and eliminating defects.

4. TPM Pillars

Historically, the TPM concept consisted of five basic pillars defined by the main initiator of the approach, S. Nakajima, and includes [22]:

1. Focus Improvement (Kobetsu Kaizen);
2. Autonomous Maintenance (Jishu Hozen);
3. Planned Maintenance;
4. Personnel Training;
5. Initial-Phase Control.

The concept was later expanded by JIPM to include eight activities based on the 5S foundation that focuses mainly on proactive and preventive techniques to improve equipment reliability called the Traditional TPM model [21]:

1. Autonomous Maintenance;
2. Focused Improvement
3. Planned Maintenance;
4. Quality Management;
5. Early Management;
6. Education and training;
7. Administrative and Office TPM;
8. Safety, Health, Environment.

Over the years, this model has evolved. Western TPM practitioners, in particular Yeomans and Millington and Steinbacher and Steinbacher, simplified the Nakajima model by eliminating or changing the pillars [38–41]. In 1995, the Society of Manufacturing Engineers developed a new model for SMEs that includes five pillars [38].

Traditional Pillars Model of TPM

At the core of TPM is the 5S method, which aims to keep a clean and well-organized work environment. The 5S approach provides the basis for well-functioning equipment; in a clean and well-organized work environment, it is much easier to find tools and parts, and it is also much easier to detect emerging problems such as fluid leaks, metal chips from unexpected wear, or small cracks in mechanisms. Thanks to this method, the employee gains greater awareness and takes responsibility for his or her workplace and strives for its improvement. The TPM pillars will not have a solid foundation and will not achieve their intended goals without the correct implementation of the 5S procedure [42].

The individual pillars of TPM are as follows [5,23,31,43–45]:

1. Autonomous Maintenance

The aim of this pillar is to properly manage and bring the equipment into perfect condition through renovation or replacement. Autonomous Maintenance is not only about independence in the field of maintenance, but also about increasing the knowledge of machines among operators who take responsibility for the adjustments and minor maintenance of the equipment they operate. Thanks to this, employees are more motivated and become more qualified. Additionally, any dangerous symptoms in the operation of machines can be detected much faster. An important element of this pillar is the CLIT method (C—cleaning, L—lubrication, I—inspection, T—tightening). It is believed that CLIT is necessary to maintain the optimal operating conditions of each piece of equipment; hence, it should be one of the operator's main activities before starting daily work. The key points of Autonomous Maintenance are employee education, active remedial action, general and autonomous inspection, and work standardization.

2. Focused Improvement

Focused Improvement involves constantly searching for opportunities to reduce problems occurring with existing machines and devices, as well as finding ways to improve the efficiency and quality of work. The key is constant cooperation between production and maintenance employees, prioritizing the most important losses and effectively eliminating them. This pillar focuses on improving the entire system with the cumulative effort of the team to eliminate waste in processes, improve daily work, or find root causes of failure (Root Cause Analysis—RCA). This pillar follows the structured support of the PDCA cycle system, which allows problems to be identified and eliminated in a systematic way.

3. Planned Maintenance

The goal of this pillar is to improve equipment efficiency and achieve zero failure, with the goal of reducing Mean Time to Repair (MTTR) and increasing the Mean Time Between Failures (MTBF). The key is to create a habit of taking care of the machines and equipment by scheduling preventive, emergency, and corrective maintenance of vases with monitoring of resource consumption. Maintenance tasks are scheduled based on predictable and/or intended failure rates. Thus, it is possible to schedule most maintenance work for times when the equipment is not scheduled for use in production. This makes it easier to control the condition of the machine and tool wear and prevent failures by detecting the problem at an early stage.

4. Quality Management

The basic concept of Quality Management is the assumption that defects occurring in processes are a failure of the organization's systems and not the operator's fault. Cost reduction is possible by detecting defects at an early stage. The process can be controlled by controlling people, machines, materials, and methods. The goal of Quality Management is to develop a mechanism for detecting non-conformities and preventing defects in production processes. Shared responsibility for operation and maintenance encourages ideas for quality improvement in all areas of work. The use of appropriate quality tools and technical analyses related to the operation of individual machine elements that are responsible for potential non-conformities affecting the final product allows for preventive measures to be taken to eliminate recurring sources of quality defects. Root Cause Analysis tools are used for this purpose, e.g., 8D, Fishbone diagram, or the 5-Why analysis method. Zero failure rate of equipment allows for significant minimization of non-conformities in production.

5. Early Management

This approach consists of two main parts—early equipment management and early product management. The main goal is zero failures and a defect-free product. Both of these approaches focus on using experience to eliminate potential failures during the planning, development, and design stages. New products must be designed to be reliable to ensure a smooth production process. New machines must be designed to facilitate easier management, from the design stage, through to the installation of machines and devices, their commissioning, and ending with their disposal. The difficulties associated with operating and maintaining the machine should be minimized. Early Management aims to implement new products/processes with minimal development time and simplification in terms of mass production.

6. Education and Training

Activities to improve employee qualifications, either through training within the company or specialized training conducted by external institutions, are the most important element in achieving TPM goals. Knowledge gaps necessary to achieve TPM objectives must be filled. This includes operators, maintenance staff, and production managers. Operators develop skills in operating the machine and identifying emerging problems, and learn proactive and preventive machine care techniques. Managers are trained in the principles of TPM and employee coaching and development.

7. Administrative and Office TPM

TPM is not only limited to production areas—it also aims to improve non-production operations, including office and administrative ones. The critical goal of implementing TPM in the non-production departments of an organization is to improve their effectiveness in fulfilling basic tasks, as well as to improve the effectiveness of the support provided by these departments. The principles of Total Productive Maintenance adopted comprehensively throughout the organizational structure facilitate the elimination of waste and increase the efficiency of management processes in the field of procurement, order processing, and planning. By applying principles such as autonomous maintenance, planned maintenance, and quality control to office processes, enterprises can reduce downtime, increase productivity, and improve employee engagement and satisfaction.

8. Safety, Health, Environment

This pillar is about maintaining a safe and healthy work environment. The goal is zero accidents, zero health damage, and zero fires. Employees must be able to perform their tasks in a safe environment without any health risks. These activities increase their level of well-being and job satisfaction, and, consequently, increase employee productivity.

5. Six Big Losses and Additional Losses

Costs related to the operation of machines and equipment are estimated to constitute between 15% and 40% of the total production or service costs. As much as 75% of these costs are related to maintenance and renovation activities or the method of use, which, of course, all have a significant impact on the final cost of the product or service. The analysis of non-production losses is most often carried out in selected areas of waste, as follows [46]:

- Overproduction: production of products without the customer's order.
- Rework: production of products requiring repair or correction.
- Inventory: material stocks greater than the minimum requirement.
- Overprocessing: too-long execution times for material flow operations.
- Waiting: idle waiting of people and machines for delayed deliveries.
- Transportation: unnecessary transport of materials.
- Motion: unproductive movements (e.g., of people).

Seiichi Nakajima initially identified six major production losses—Six Big Losses (in three subgroups)—the elimination of which would result in improved equipment use and lead to world-class production [5,24,47,48]. Brief descriptions of them are provided below.

a. Availability Loss:

    1 Unplanned Stops: A failure in the machine requiring corrective action. Failures can be divided into those that occur unexpectedly and rarely, and cyclical ones, i.e., those that occur periodically on a given machine or a group of similar machines. In the case of cyclic failures, it is necessary to find and eliminate the source of their occurrence.

    2 Setup and Adjustment: In addition to time loss, they also involve wastage of material in the form of defects produced during setting parameters after retooling. The solution is to use the SMED (Single Minute Exchange of Die) method, which allows for shortening of all changeovers to 10 min.

b. Effectiveness Loss

    3 Small Stops (usually up to 5 min): Situations in which the machine does not work or does not fulfill its function, and the reason for this condition is not a failure. These are situations caused by, for example, a lack of raw material or a blockage. Breaks are difficult to define, but, at the same time, they can constitute a large percentage of unused planned working time.

4 Slow Running: Reducing the operating speed of the machine, e.g., due to a fault or a too-high operating speed, which may result in lower product quality or faster wear of the machine.

c. Quality Loss

5 Production Defects: Producing products of a quality that does not meet customer requirements. The result is an increase in the time used to produce defective products, their possible repair, and material losses.

6 Reduced Yield: Losses measured in materials and time from the moment of preparation for the start of the process until the process stabilizes.

Further work in this field, carried out by various researchers, has allowed for the identification of more losses of a sporadic or chronic nature, which include the following [5,46]:

- Consumable losses: financial losses resulting from the obsolescence of equipment wear parts, which result in a loss of production speed, which causes production times to exceed normal cycle times, which affects OEE.
- Management losses: the loss increases with incorrect communication within the organization, affects increased production time compared to normal cycle time, and affects the achieved value of the OEE.
- Motion losses: the losses increase when there is a difference in the manual skills of operators, and this results in increased production time and reduced value of the OEE.
- Distribution losses: Man–hour losses are actually due to mismanagement in the supply chain or losses occurring due to the inability to automate. This effects on-time delivery.
- Energy losses: Losses related to inefficient use of electricity, gas, etc. This affects OEE.
- Tool losses: Financial losses caused by aging or damaged equipment. This adversely affects cost.
- Yield losses: time lost for the replacement and purchase of new materials resulting from the non-compliance of the received material with the requirement.
- Line organization losses: Waste in waiting time losses involving multi-process and multi-stand operators.

6. Effectiveness Indicators

The goal of the TPM concept is to maximize equipment efficiency. Below are six criteria for the indicated machines to assess the degree of effectiveness of their use in a given process [5,41].

1. Reliability: The ability of the machine to perform assigned tasks in a given period of time, under specific conditions. It is described by the MTTF (Mean Time to Failure) indicator or the average number of failures of a given device in a specific time period.
2. Ease of maintenance: A feature of the object that determines how easy it is to keep the machine in working order or restore it to a state in which it is able to perform its functions. The indicator used to quantitatively describe it is MTTR (Mean Time to Repair).
3. Availability: The degree of use of the planned time; in other words, the tendency of the device to remain in a state in which it can perform planned activities for specific conditions at a specific time. It should be assumed that all necessary resources are available. Therefore, the availability of the machine is not affected by situations in which it is, for example, in forced standstill.
4. Support capacity: Waiting time for a repair that determines the ability of maintenance to provide support during a machine failure (time to reach the breakdown, waiting for spare parts, access to the machine, etc.), as described by the MDL (Mean Logistic Delay) indicator.
5. Operational availability: time used directly to perform operations.
6. Mean Time to Maintenance (MTTM): the average time between repairs and maintenance, determined for a specific time period.

One of the assumptions of the TPM concept is to set specific goals such as numerical values of the main indicators for measuring the effectiveness of processes carried out on specific machines, designated for a defined period of time, or the effectiveness of implementing the TPM concept itself in the organization. Regardless of the chosen approach, the long-term observation of individual workstations and the accuracy of the collected data is necessary to determine the values of the indicators. Each indicator characterizes different issues. Combining them can provide a complete picture of a team's effectiveness in managing incidents and potential areas for improvement in maintaining equipment operation. Monitoring TMP indicators allows you to plan the time for inspections or the preventive replacements of key parts on priority machines, control the effectiveness of maintenance activities in the organization, measure progress in shortening the time to repair failures in the organization, or measure progress in implementing Autonomous Maintenance activities.

6.1. OEE Indicator

TPM defines tools for measuring the effectiveness of implementing the concept itself in the organization—one of them is the OEE (Overall Equipment Effectiveness) indicator. OEE allows for the percentage of the utilization of machinery to be calculated, which is the ratio of Fully Productive Time to Planned Productive Time. According to S. Nakijama, OEE measurement is an effective way to analyze the performance of a single machine or an integrated production system [24]. OEE is a composite indicator presented as a product of availability, utilization, and quality indicators. There are many different interpretations and ways of calculating this indicator. According to the ISO 22400-2 standard "Automation systems and integration [49,50]. Key performance indicators (KPIs) for manufacturing operations management", OEE is calculated using the following formula:

$$\text{OEE} = \text{Availability} \times \text{Effectiveness} \times \text{Quality} \tag{1}$$

OEE takes into account all losses (Availability, Effectiveness, Quality), which gives a measure of actual productive production time. The availability rate is the ratio of the planned working time at a given time to the actual working time of the machine in the same period.

The availability is calculated using the following formula:

$$\text{Availability} = \text{Run Time}/\text{Planned Production Time} \tag{2}$$

$$\text{Run Time} = \text{Planned Production Time} - \text{Stop Time} \tag{3}$$

Effectiveness includes Effectiveness Loss, which includes all factors that cause production processes to operate at slower speeds than the maximum possible during operation (including slow cycles and short stops):

$$\text{Effectiveness} = (\text{Ideal Cycle Time} \times \text{Total Count})/\text{Run Time} \tag{4}$$

Ideal Cycle Time is the theoretical fastest possible time to manufacture one piece.

Quality is calculated as the ratio of Fully Productive Time to Net Run Time. In practice, it is calculated as

$$\text{Quality} = \text{Good Count}/\text{Total Count} \tag{5}$$

where Good Count time means only Good Count manufactured with no Stop Time, as fast as possible, and Total Count means fastest possible time for Total Count.

Substituting equations for Availability, Performance, and Quality into Equation (1), the result is

$$\text{OEE} = (\text{Good Count} \times \text{Ideal Cycle Time})/\text{Planned Production Time} \tag{6}$$

OEE is tightly coupled to the TPM goals of no breakdowns, no small stops or slow running, and no defects. OEE is useful as both a benchmark and a baseline. As a baseline, the OEE indicator can be used to track progress over time in eliminating waste from a given production asset. As a benchmark, OEE can be used to compare the performance of the given equipment with industry standards or with the results of work on various shifts in the organization [51]:

1. Perfect Production (OEE = 100%): only highest quality, maximum output speed, no downtime;
2. World Class Production (OEE = 85%): world-class for discrete manufacturers, suitable long-term goal, high output/quality ratio;
3. Typical Production (OEE = 60%): typical for discrete manufacturers, substantial room for improvement, data often includes periods of good output or quality;
4. Low Production (OEE = 40%): common baseline for sites starting OEE project, low score, easily obtained improvements by reducing largest sources of downtime.

World Class OEE is Seiichi Nakajima's OEE target of 85%. According to Nakajima, the availability of machines should be above 90%, the utilization of machines in the available time should be above 95%, and the quality of the products produced during this time should be above 99% [24]. Another specificity of the OEE indicator is that a low level of one of the factors causes a significant reduction in the final OEE value.

Each company should set its own goals regarding the value of the OEE indicator, especially in each of its components separately. A large number of changeovers is characteristic of small-batch production. Of course, this reduces OEE, but, on the other hand, it reduces the worst type of waste—inventories. Each organization should establish its own Company Class OEE, which will be adapted to the specificity of the organization and will motivate employees to look for improvements in the machine-operation process.

6.2. MTTR, MTTF, and MTBF Indicators

The most frequently used indicators related exclusively to technical problems of the tested production line are MTTR (Mean Time to Repair), MTTF (Mean Time to Failure), and MTBF (Mean Time Between Failures). These indicators belong to reliability measurement techniques originating from the military and aviation, where they often operate on very large data sets [41,52].

MTTR (Mean Time to Repair) is the average time it takes to repair or maintain a machine, assuming that the activities are performed using appropriate resources, in accordance with the manufacturer's recommendations. It is counted from the moment the production is stopped (production line, machines) due to a failure.

$$\text{MTTR} = \text{failure time}/\text{number of recovery events} \tag{7}$$

This coefficient is very important, primarily due to the calculation of the time related to the speed of fault removal. It is also worth adding that MTTR shows how and at what pace the maintenance department can operate and how quickly qualified employees are able to restore the machine to full efficiency.

MTTF (Mean Time to Failure) determines the average operating time of a device from the beginning of its operation or from its last repair until the next failure occurs, assuming that the failure cannot be repaired.

$$\text{MTTF} = (\text{available uptime} - \text{failure time})/\text{number of events} \tag{8}$$

MTBF (Mean Time Between Failures) is the most commonly used indicator. Its main purpose is to determine the efficiency of machines in terms of maintenance. The MTBF indicator determines how often "something" that can be repaired breaks down. This is the average failure-free operation time, i.e., the period during which the device can operate without interruption (failure).

$$\text{MTBF} = \text{MTTR} + \text{MTTF} \quad (9)$$

It is also worth adding that all other indicators should strive to eliminate failures and, thus, maximize the value of MTBF indicators. Based on the MTBF indicator, you can monitor the failure rate of machines and plan preventive actions for key machine parts (see Figure 4).

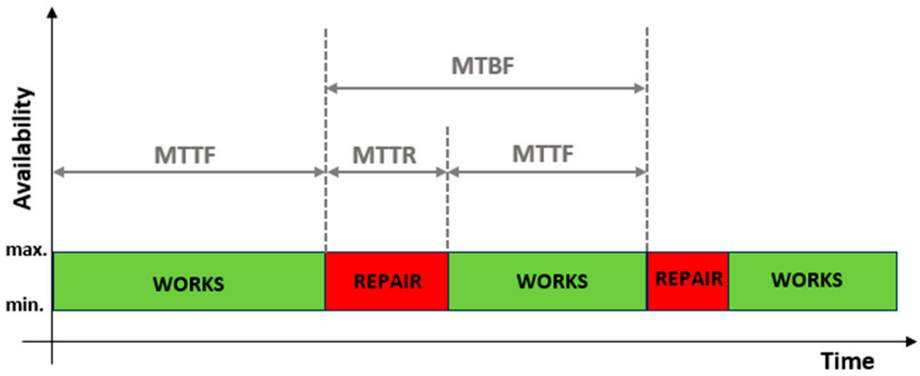

Figure 4. MTTF, MTBF, and MTTR in production time. Data from [53].

7. Stages of Implementing the TPM Concept in the Organization

7.1. Traditional Concept of TPM Implementation in the Organization

The Japan Institute of Plant Maintenance and Seiichi Nakajima developed a 12-step TPM-implementation model, covering 4 implementation phases, which has become widely used in manufacturing industries worldwide (see Figure 5) [24,43,45,53].

Step 1: Declaration of introducing TPM by top management

The declaration of introducing TPM in the organization should be made by top management, which will demonstrate commitment to and support of the implementation, maintenance, and improvement processes. The declared policy and goals of TPM should be communicated to all employees of the organization using a common means of communication, e.g., e-mail, notice board, or internal bulletin. At this stage, it is necessary to develop a plan for integrating TPM within the organization's business strategy.

Step 2: Introductory education and campaign

It is very important that all employees are trained in TPM in order to understand the TPM concepts and terminology used in this area. Training must be designed to ensure that each employee understands their role and responsibilities in accordance with the scope of work they perform. The training can be delivered through various means such as workshops and webinars.

Step 3: TPM promotion in the organization by formation of committees

A multifunctional committee should be created to promote and monitor TPM activities in the organization. It is necessary to assign the responsibility for TPM implementation to individual committee members. The communication plan used should ensure that TPM activities are understood and supported throughout the organization.

Step 4: Setting elementary TPM principles and targets

A detailed TPM-implementation plan should include an implementation schedule and designated milestones. In order to measure the effectiveness of TPM activities, baseline values of key performance indicators (KPIs) should be defined. Business goals should be consistent with the SMART principle, which includes being Specific, Measurable, Achievable, Relative, and Time-bound.

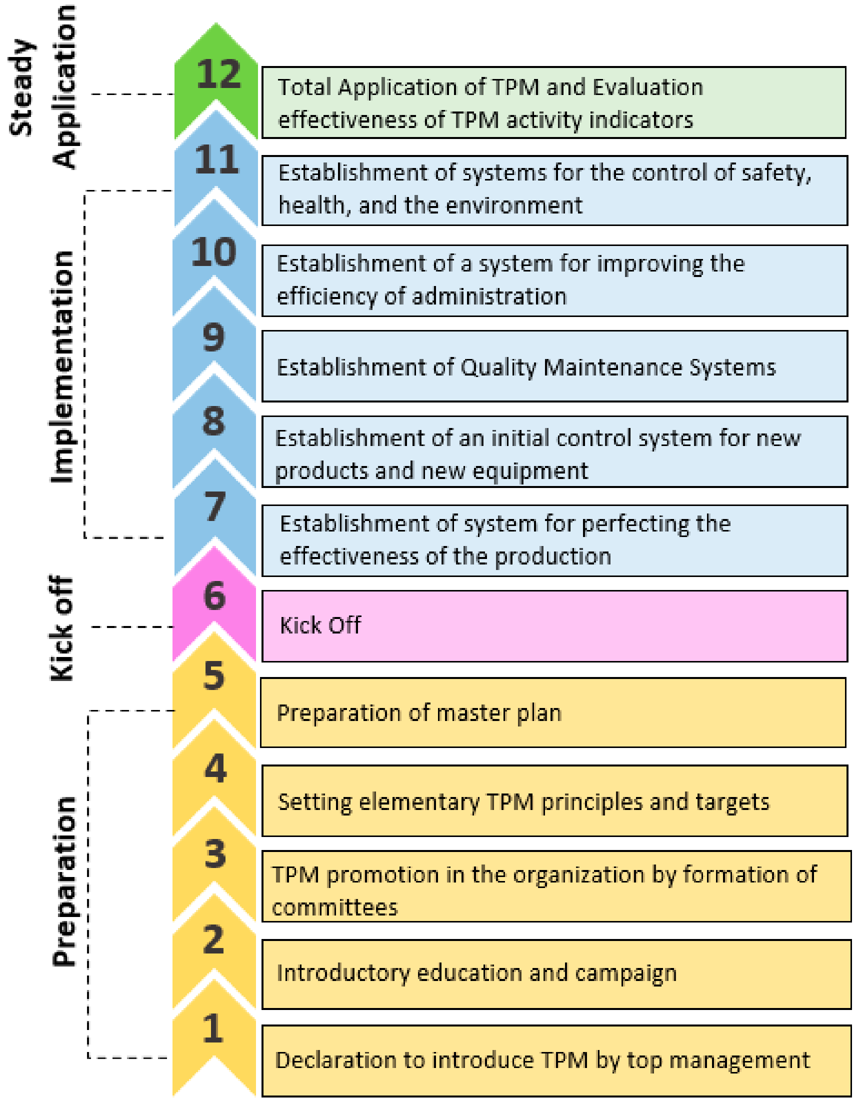

Figure 5. Twelve steps for implementing Total Productive Maintenance. Data from [24,43,45,53].

Step 5: Preparation of master plan

The master plan should include key milestones, responsibilities, and a target date. In general, the timeline of a TPM project is 3 years, but it depends entirely upon the organization's management. The basis of the master plan is the development of annual, quarterly, and monthly plans.

Step 6: Kick off

In this phase, top management announces the start of the TPM project in the presence of all stakeholders. Information is also provided to stakeholders, i.e., customers, traders, and investors. It is important to note that the actual implementation of TPM begins later, and all of the steps preceding it are aimed at preparing specific foundations.

Step 7: Establishment of system for perfecting the effectiveness of production

The stage is based on the implementation of four pillars in order to improve production efficiency and effectiveness.

1st Pillar: Focused Improvement (Kobetsu Kaizen): Special teams develop a focused improvement program to identify and eliminate equipment-related failures. Employees are trained in problem-solving techniques.

2nd Pillar: Autonomous Maintenance (Jishu Hozen): The implementation of this pillar takes place in seven steps. The main goal is to educate operators so that they can independently perform minor maintenance activities, like lubricating, cleaning, etc., on their own, thus maintaining equipment at optimal conditions.

3rd Pillar: Preventive Maintenance: A preventive maintenance system is developed to maintain a zero-failure state. Corrective, periodic, or predictive maintenance practices are implemented, and a preventive maintenance plan is developed.

4th Pillar: Training and Education: All team members receive training on all pillars, skills, and activities as required.

Step 8: Establishment of an initial control system for new products and new equipment

This is the 5th Pillar of TPM, which aims to learn from the organization's previous experiences. This allows all new equipment to quickly achieve the desired results. It is possible to smoothly achieve the rated output of the equipment in a short time.

Step 9: Establishment of Quality Maintenance Systems—QMS

In this step, the 6th Pillar is established. Once quality systems are established and optimal levels are achieved, all processes are standardized to achieve optimal conditions.

Step 10: Establishment of a system for improving the efficiency of administration

At this stage, TMP is implemented in departments supporting the production department—administration and offices. It is necessary to develop a system for data collection, analysis and reporting, and maintaining and analyzing equipment history and procedures for equipment modification and replacement.

Step 11: Establishment of systems for the control of safety, health, and the environment. At this stage, the Safety, Health, and Environment pillar is established to help maintain a zero-accident status. It is based on the development of procedures for the safety of equipment operation and maintenance, and the implementation of measures to minimize environmental impacts.

Step 12: Total application of TPM and evaluation effectiveness of TPM activity indicators

In this phase, KPIs are developed to measure the effectiveness of TPM activities, establish procedures for collecting and analyzing data regarding the KPIs, and reviewing and evaluating the effectiveness of TPM activities. The TPM-improvement process is continued. Previous experience is used to achieve higher goals in the coming years.

7.2. Other Concepts of TPM Implementation

There are many other TPM-implementation approaches suggested by various practitioners and researchers. The implementation methodology depends on the type of organization, work environment, and organizational goals related to acquiring strategic production competences. Naguib proposed a five-step implementation plan, which was described in the publication [54].

The model presented by Steinbacher and Steinbacher is a certain simplification of the approach promoted by Nakajima. The five-pillar model presents the principle that the implementation process at the highest level requires initialization, implementation, and institutionalization. In this model, training and education are an integral part of the other pillars and are not independent pillars, as in the Nakajima model [55,56].

According to Pirsig, the TPM-implementation program is divided into four main elements: training, decentralization, maintenance prevention, and multi-skilling, and seven unique areas (see Figure 6) [23].

The organization Productivity Inc. has developed an alternative TPM rollout methodology consisting of eight stages: Pull and Readiness, Management Awareness, Value Stream Analysis, Site Plan Design, Operator Training, Eight Pillars Execution, Audit Progress and Countermeasures, and Sustainment (see Figure 7) [57].

Practitioners of TPM implementation in organizations indicate that the implementation is generally carried out in five steps (see Figure 8) [58].

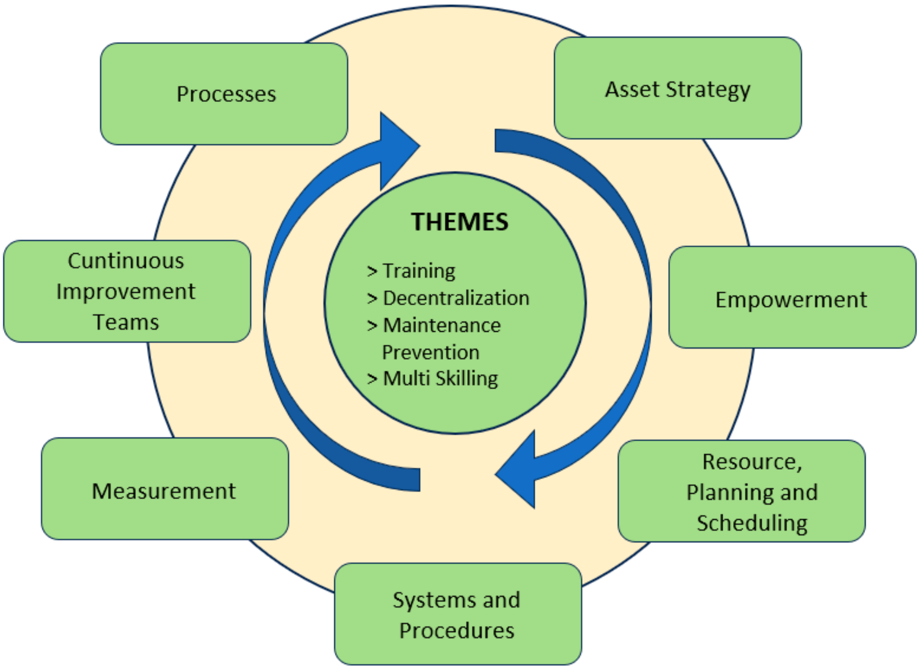

Figure 6. Pirsig's model of TPM implementation [23]. Reprinted with permission from Ref. [23]. Copyright 2009 Springer Nature.

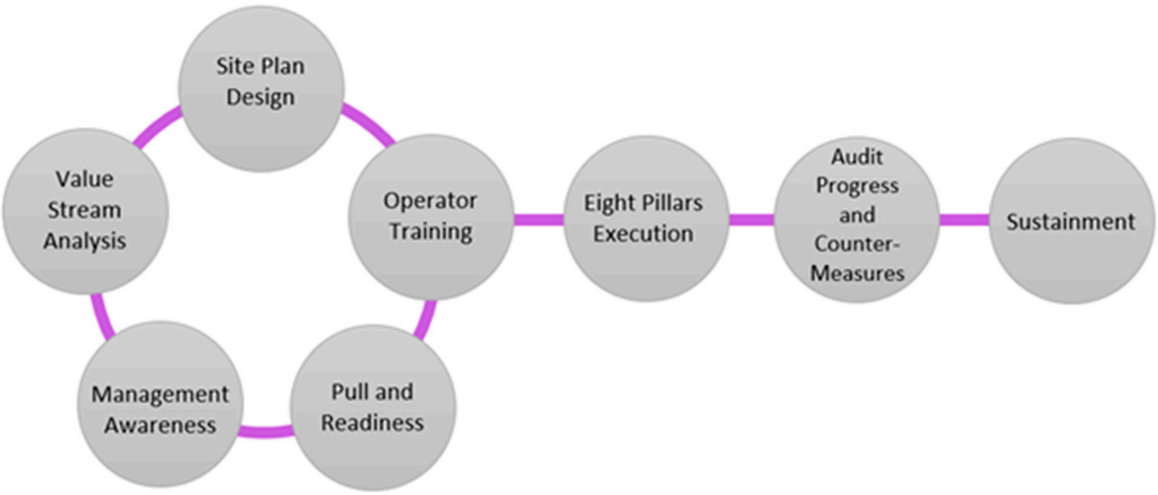

Figure 7. TPM rollout [57]. Reprinted with permission from Ref. [57]. Copyright 2023 Productivity Inc.

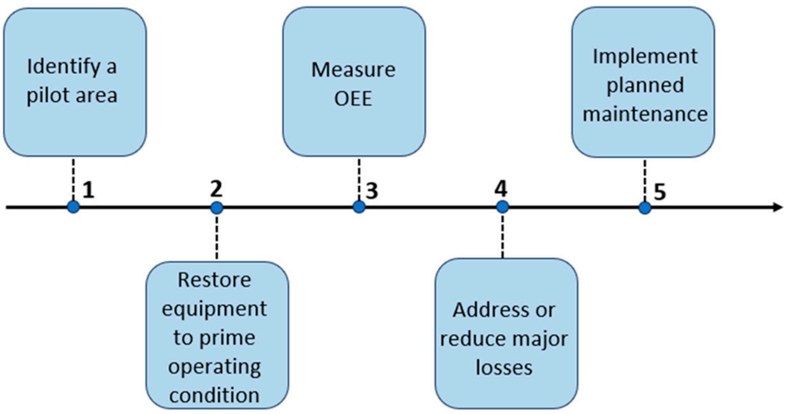

Figure 8. Practical TPM-implementation model. Adapted from [58].

An Ideal TPM Methodology (ITPMM) for manufacturing organizations has been categorized into three phases: Introduction, TPM initiatives implementation, Standardization. The assumption is that the method is to provide greater possibilities of adaptation and modification depending on the needs of the organization. The respective phases of ITPMM are described in Figure 9 [23]:

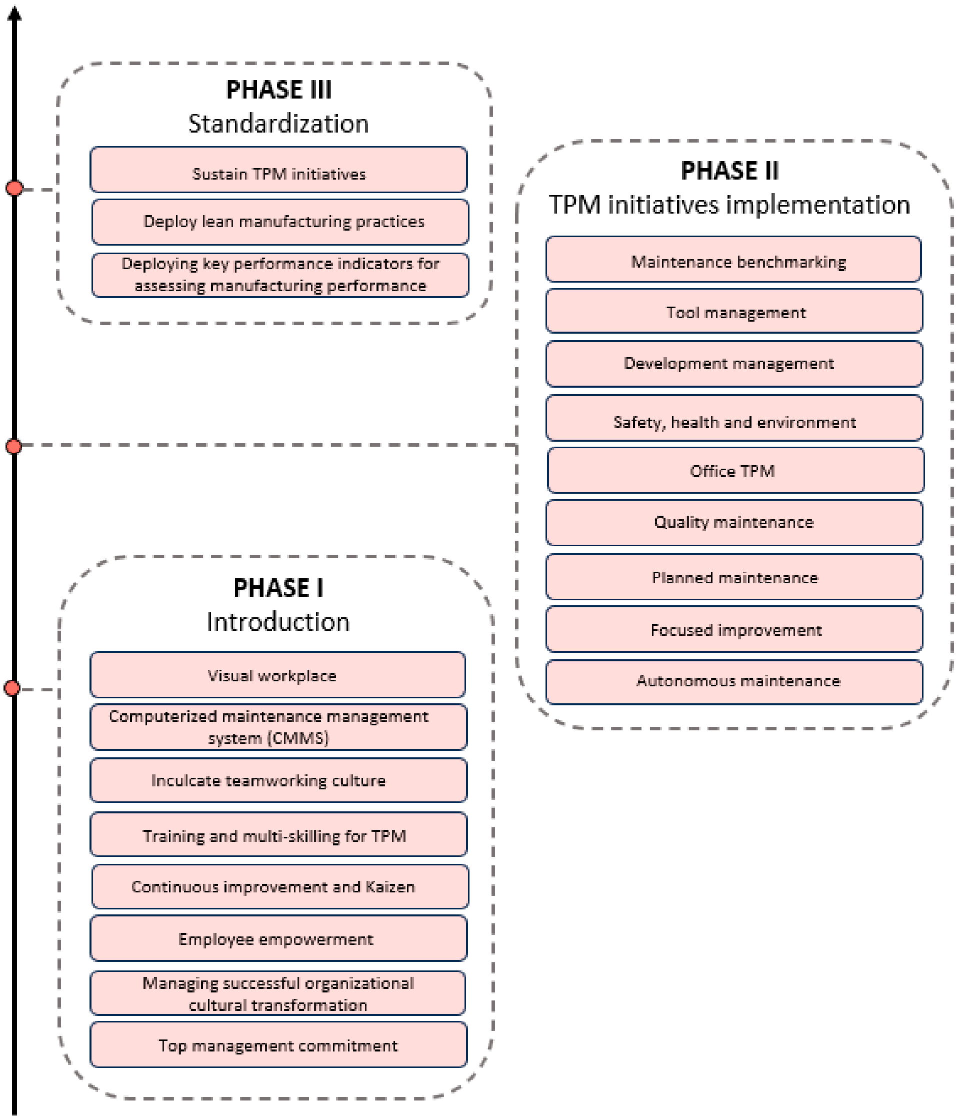

Figure 9. Ideal TPM Methodology (ITPMM) for manufacturing organizations [23]. Reprinted with permission from Ref. [23]. Copyright 2009 Springer Nature.

8. Barriers in TPM Implementation

Although the TPM concept has been known and used for many years, the difficulties encountered in its implementation mean that few organizations have achieved full implementation. This is due to changes in the nature of the maintenance department's work, new expectations towards employees, and completely different relations between departments. Therefore, before applying the TPM concept, each company should thoroughly analyze and understand its assumptions, taking into account the requirements and problems specific to the industry, production methods, and the type and condition of its machines. Understanding the risks can be a significant key to achieving implementation success of the TPM strategy.

In the literature, you can find various approaches to defining TPM-implementation barriers. The varied classification and nomenclature of obstacles results from the experience or practice of the authors.

Poduval and Pramod in the publication [59] identified 21 barriers to TPM implementation: for example, lack of commitment from top management, lack of knowledge of TPM, need for training, and an unavailability of standard operating procedures.

Based on an extensive literature review, Singh et al. defined 11 main barriers to the implementation of the TPM concept [60].

The barriers affecting the implementation of the TPM concept, as identified in an organization that was a beneficiary of the JIPM World Class Award, are included in seven groups: communication and strategy, senior management role, employee participation, effective organization goals, education and training, a structured approach to TPM implementation, and reward and recognition [44].

Attri et al. classified all barriers affecting TPM into five groups: behavioral barrier, human and cultural barrier, strategic barrier, operational barrier, and technical barrier [61]. Ahuja and Khamba introduced two additional groups: financial and departmental barriers [5].

The behavioral obstacles include the following:

- Resistance from employees to adapt to proactive, innovative management concepts;
- Difficulties working in interdisciplinary teams;
- Lack of employee motivation to achieve specific goals;
- Lack of loyalty;
- Insufficient efforts to periodically update employees' skills;
- Lack of willingness of employees to expand their knowledge;
- Resistance to accepting changes;
- Fear of job loss due to technological improvements.

The human and cultural obstacles include the following:

- Inability to adapt employees to the goals and tasks of the organization;
- Lack of professionalism, including lack of consistency in actions;
- Non-flexible approaches, non-adaptable attitudes;
- Inability of top management to motivate employees;
- Low skill base is also a deterrent in terms of accepting changes in the workplace;
- Marginal participation of employees in decision making in the organization.

The strategic/organizational obstacles include the following:

- Inability of the organization to introduce cultural changes;
- Inability of the organization to manage change comprehensively;
- Lack of involvement of top management;
- Lack of communication regarding TPM;
- Lack of understanding of TPM principles;
- The organization's inability to change the mindset of its workforce to achieve employee engagement;
- Inappropriate pace of TPM implementation;
- Too many improvement activities implemented at the same time;
- Lack of appropriate employee-reward mechanisms;
- Lack of a focused approach, imperfection of the master plan;
- Resistance of middle management to grant authority to lower-level operators—fear of losing power and respect;
- Inability of the organization to improve employee competences;
- Lack of employee awareness of the TPM concept;
- Lack of evaluation and monitoring mechanisms, e.g., OEE, RONA (return on net assets), ROCE (return on capital employment).

The operational obstacles include the following:

- General acceptance of high levels of defects;

- Non-adherence to standard operating procedures (SOPs);
- Limited rights of operators to take action related to the equipment;
- Lack of check sheets of planned maintenance to conduct routine maintenance jobs efficiently;
- Lack of implementation of safe work practices;
- Assuming too short a time for the improvement process;
- Emphasis on repairing equipment rather than on preventive measures.

The technical/technological obstacles include the following:

- Little emphasis on improving production capabilities;
- Inadequate system for assessing and improving reliability;
- Insufficient infrastructure;
- Inadequate computerized maintenance management systems (CMMS);
- Lack of mechanisms for assessing production inefficiencies;
- Poor flexibility of production systems;
- A workforce with insufficient skills in relation to new technologies;
- Lack of adequate training in diagnosing problems;
- Poor energy efficiency of production systems.

The financial obstacles include the following:

- Lack of additional resources at the beginning of TPM implementation;
- Too few resources to support improvement initiatives;
- Lack of an appropriate motivation system.

The departmental obstacles include the following:

- Insufficient inter-departmental cooperation between maintenance and production departments.

The above-mentioned analysis and research results allow us to determine that the most common barriers related to the implementation of TPM strategies in organizations are resistance to accepting changes, inability of top management to motivate employees, inability of the organization to introduce cultural changes, inappropriate pace of TPM implementation, and inappropriate initiatives to assess and improve the reliability of production systems.

9. Key Successful Factors and Benefits in TPM Implementation

There are many success criteria for successfully implementing and improving (developing) TPM strategies in organizations. The critical success factors can be classified into three broad categories:

1. Human-oriented factors [24,27,62–72]:
    - Long-term commitment of senior management;
    - Cross-functional teamwork;
    - Employee involvement.
2. Process-oriented factors [24,64,65,68,70,71,73,74]:
    - Application of the 5S program;
    - Resource planning;
    - Monitoring and controlling maintenance KPIs;
    - Use of pilot reliability improvement projects;
    - Early hardware-design considerations;
    - Early product-design considerations;
    - Carrying out planned/preventive maintenance;
    - Documenting maintenance works.
3. Organization-oriented factors [63–65,69–71,73–77]:
    - Aligning TPM goals with the organization’s goals;
    - Setting organizational goals;
    - Culture change;

- Using the continuous-improvement approach;
- Providing on-the-job training;
- Conducting benchmarking activities;
- Supporting the activity of small groups towards the implementation of autonomous maintenance;
- Ensuring information availability;
- Establishing a reward system.

Realizing the potential of TPM strategy requires the full integration of TPM goals and tasks within the organization's business strategy. There is a huge need to support initiatives that facilitate TPM implementation, which include engaged leadership, strategic planning, and interdisciplinary training. A holistic approach to the TPM concept requires focusing on the benefits for both the organization and employees. Organizations must be aware that unrealistic schedules and aggressive action plans can lead to loss of employee motivation during a long TPM-implementation period. The most important thing is to learn from mistakes and make further improvement efforts.

It is particularly important to emphasize the value of activities resulting from the implementation of TPM in terms of reducing risks related to occupational safety or the impact of machine failures on the environment. This aspect is particularly important and topical in the scope of the European Parliament's directive regarding corporate reporting on sustainable development.

Research shows that the implementation of the TPM method brings a number of benefits to the company: a 25–30% reduction in the costs of maintaining technical infrastructure, a 70–75% elimination of failures, a 35–45% reduction in downtime, and a 20–25% increase in production [78,79]. The systematic implementation of the assumptions of each of the eight pillars of TPM brings measurable benefits to the entire enterprise, thus playing an important role in improving the organization's operations. A summary is presented in Table 2.

Table 2. Organizational benefits from implementing individual pillars of the TPM [9].

Pillar—Main Assumptions	Benefits for the Organization
Autonomous maintenance Independence of employees in terms of maintenance	• Increasing knowledge of devices • Increased motivation and qualifications of operators • Ensuring proper maintenance of equipment • Quick and efficient identification of any dangerous symptoms in the operation of the device • Freeing maintenance workers for higher-level tasks
Planned maintenance Planning maintenance activities based on predicted and/or measured failure rates	• Significant reduction in the amount of unplanned downtime • Planning maintenance activities when equipment is not in production • Continuous monitoring of resource consumption • Effective management of maintenance costs
Quality assurance Detecting and preventing errors in production processes	• Focusing on quality issues through improvement projects focused on removing sources of defects • Reducing the number of defects • Reducing costs thanks to early detection of faults • Increasing customer satisfaction by improving product quality and consistency
Focused improvement Achieving regular, incremental improvements in device performance as a result of constant cooperation between production and maintenance	• Eliminating waste • Improvement in daily work • Identification of root causes of failures • Connecting the organization's collective talents to create a driving force for continuous improvement

Table 2. *Cont.*

Pillar—Main Assumptions	Benefits for the Organization
Early maintenance planning Guided by practical knowledge to plan maintenance activities for new equipment	• Verification of the profitability of the modernization, repair, or purchase of a new device • Planned performance levels of new devices are achieved much faster • Simplifying the maintenance phase thanks to hands-on inspection and employee involvement before installation • Facilitating financial planning for maintenance services
Employee development and training Filling knowledge gaps necessary to achieve TPM goals	• Independence of operators in making minor repairs • Development of hard and soft skills of employees • Changes in the organization's operations from reactive, through preventive, to predictive • Personal motivation
Safety and environment Keeping a safe and healthy work environment	• Elimination of potential health and safety hazards • Minimizing the risk of environmental influences in case of failure
Office TPM Application of TPM to administrative areas	• Improving procedures related to order processing, documentation standards, and scheduling • Improving communication between individual departments • Elimination of waste in the administrative area.

10. Literature Review on Some Organizations That Have Implemented the TPM Approach

The available data indicate that less than 10% of organizations that implement TPM into their structure achieve implementation success. What are the key success factors, and what benefits of TPM implementation are identified in various organizations? The answers to these questions are in this section. Literature data indicate that some researchers concentrated on one or more of the TPM tools, while others implemented all of the TPM pillars [80].

Ireland and Dale identified the key success areas as the high involvement of top management and the reduction in the organizational structure. A rubber manufacturing organization that is a beneficiary of the JIPM award and uses the above key to success spent GBP 0.40 million on TPM implementation and realized over GBP 2 million as benefits within three years of the implementation process [81].

In South Africa, there have been several TPM-implementing successes in the pulp and paper industry. In Entra Mill, a mill run by Sappi as a management aid, a graphical presentation of trends in quality progress, costs, and supply levels was introduced. The main reason for the successful implementation of TPM in Entra Mill is due to the good level of knowledge of TPM among employees, and the commitment of top management. The benefits are improvements in equipment availability, quality, and a reduction in the cost [80].

Lawrence, who analyzed TPM implementation in US companies, stated that in many cases, the most difficult, but, at the same time, key aspect is the change in the organizational culture. The support of top management, provision of a training system, and adjustment of remuneration systems had a direct impact on reducing overtime at work, improving employee punctuality, increasing equipment availability, and minimizing unplanned tasks [82].

The market-leading companies Ford Motors, Harley Davidson, Allen Bradley, Eastman, Kodak, and Texas Instruments have experienced a 50% or greater reduction in downtime and inventory and an increase in on-time deliveries thanks to the implementation of TPM. Texas Industries identified an 80% increase in production in some areas. Kodak reported that a USD 5 million investment in a successful TPM program resulted in a USD 16 million increase in profits. The success factor in these organizations was developing a practical schedule, developing relevant measures of performance, and continuously monitoring and publishing benefits in financial terms [80].

The implementation of TPM in Whirlpool, Ohio, resulted in a 21% increase in production and massive improvements in overall equipment effectiveness. The major factor for TPM success is interdepartmental cooperation [79].

Tsang and Chan studied TM implementation in a factory producing semiconductors in China. The implementation process took place in three phases over 5 years. The benefits achieved include a 24% drop in breakdowns and a clean and tidy workplace. The most important success factors are commitment by top management and the cultural change in organization [83].

In India, Dogra et al. implemented the four pillars of TPM (Autonomous Maintenance, Planned Maintenance, Kaizen, and Training and Education) in a cold rolling factory. The company obtained an OEE of 83.95% after 18–20 months of implementation. TPM adoption improved communication between departments at all levels [84].

Kumar et al. conducted an empirical study in industrial area. For a pilot area of 10 machines, 4 of them had an OEE of 15% to 60% with productivity ranging from 9% to 34%. Thus, the main causes of downtime and loss of productivity in the studied area were identified [85].

Iftekhar applied four pillars TPM (Planned Maintenance, Kaizen, Autonomous Maintenance, and Education and Training) at a Bangladeshi manufacturing company. One year after implementation, a 50% reduction in time lost, a 13% increase in availability, a reduction in MTTR, and an increase in the MTBF period were observed [86].

A TPM case study was conducted involving the world's largest automotive battery manufacturer. The activities implemented over three years included establishing basic equipment and technical equipment care standards in order to build high-performance workplace capabilities in 15 manufacturing facilities globally. The outcomes were a reduction in the baseline equipment unplanned downtime of 25% (all-inclusive), improved critical equipment reliability by 300%, and the building of internal sustainment capabilities. Another case study of a major industrial and communications wire and cable company examined the 5-year implementation of a Lean and Total Productive Maintenance program in three facilities company-wide. The following effect was achieved: reliability improved by 48%, the OEE of critical equipment improved from 48% to 75%, and numerous equipment-redesign projects in support of safety and the new improved OEE were completed [87].

The available literature indicates that the TPM concept has implementation potential in organizations that operate entirely in non-production areas, e.g., services, analytical research, the hotel industry, health care, education, transport, and construction. An example is the research of T.H. Haddad and A.A. Jaaron, conducted on the implementation of TPM in hospital operations in order to increase the availability of medical devices and reduce their failure rate [88]. Similar research was described by R. Chompu-Inwai, S. Tipgunt, and A. Sunawan concerning the effects of the pilot implementation of TPM for dental departments, which allowed the level of use and availability of dental devices to be increased, and unplanned equipment downtime to be reduced [89], or research to be conducted by A.Y. Ali on the applicability of TPM in a newspaper-printing house [90]. The results obtained in each of the above-mentioned articles indicate a high potential for implementing the standardization of a number of control activities in the TPM area.

The initial assessment of the possibility of implementing TPM in the chemical laboratory indicates the potential to shape new possibilities in the field of the rational management of resources and, consequently, finances. Lower operating costs, longer equipment life, lower overall maintenance costs, process improvement, waste reduction, and increased productivity can contribute to overall organizational excellence and competitiveness. The implementation of TMP in organizations combining two areas—production and non-production—may result in achieving a synergistic effect that will contribute to increased flexibility in relation to changing market requirements and customer needs [9,79].

Based on these examples, five main conclusions can be drawn characterizing the effect associated with the implementation of the TPM concept in organizations:

1. TPM can be used in any industry, regardless of its size.
2. TPM shows high adaptation potential also for non-production organizations.
3. TPM implementation may include one or more TPM pillars.
4. TPM can be based on a single assessment tool. OEE indicator is the most commonly used evaluation technique because it indirectly covers quality, performance, and availability.
5. The success of the TPM-concept implementation depends on the organization's capability for teamwork.

11. Future of the TPM Concept

The development of Industry 4.0 has necessitated breakthrough changes in production processes based on a on big data analysis technology. Valamede and Akkari conducted research on the integration of selected Lean Manufacturing tools (JIT, Kaban, Poka-Yoke, VSM, Kaizen, TMP) with Industry 4.0 technologies. The attributes of Lean 4.0 were classified into five dimensions [91]. TPM was the tool that showed the greatest potential for convergence with digital technologies; the interaction points are shown in Figure 10.

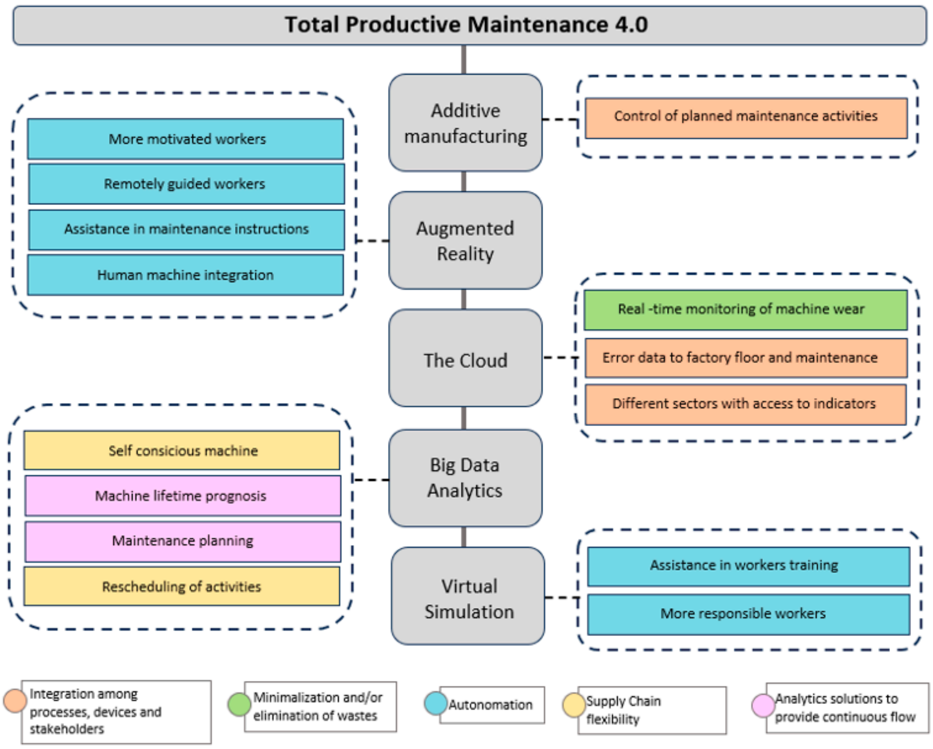

Figure 10. Correlation between TPM and 4.0 technologies, including attributes of Lean 4.0. Adapted from [91].

Aiming to eliminate waste in the production processes, Lean Manufacturing, including TPM, accelerates the production flow, facilitates the digitization of production stages, and emphasizes visual control, making the identification of equipment failures much easier.

Due to the continuous evolution of the manufacturing environment, organizations must stay up to date with industry trends and innovations in order to successfully adapt TPM assumptions to the following changes. The literature indicates that one of the possible trends and innovations may be the use of IoT and Smart Sensors in TPM. Providing real-time data on equipment performance and condition will allow for active monitoring of equipment condition and may facilitate informed decision making regarding implementation of targeted improvement strategies [92].

Another future direction of maintenance development is Sustainable Total Productive Maintenance (STPM), a new concept created in 2021. It aims to support orientation towards sustainable development from the perspective of sustainable maintenance. Currently, STPM is seen as a complement to the traditional TPM concept. As part of STPM, in the general context or maintaining the sustainable development of organizations in Industry 5.0, the following research directions are indicated: research in augmented reality and virtual reality [93].

12. Conclusions

Dynamically changing market needs and constantly growing global competition give impetus to many organizations around the world to adopt effective and efficient maintenance strategies, including TPM methods. The correct implementation of strategic initiatives and methods, each adapted to the operating reality of a given organization, allows for better use of the capabilities of devices and people. The holistic implementation of the TPM concept in the organization should lead to the establishment of strategic, proactive, and progressive practices, enabling the avoidance of system failures and failures related to the existing equipment. For both production and non-production areas, the importance of the TPM method is similar. Its implementation, assuming the correct use of its tools, allows the organization to

- Achieve sustainable organizational growth;
- React to changes while maintaining the company's competitiveness;
- Synchronize processes;
- Achieve greater operational flexibility;
- Improve the organization's culture;
- Improve productivity and product quality;
- Reduce costs;
- Minimize investments in new technologies and maximize the return on investment;
- Optimize inventory levels and process implementation times in order to achieve optimal availability/operability of devices;
- Minimize the impact of external factors such as strong competition, globalization, and increases in the costs of raw materials and energy;
- Solve the internal problems of the organization, e.g., low productivity, large numbers of customer complaints, high defect rate, failure to meet delivery/service deadlines;
- Ensure the more effective use of human resources;
- Make work simpler and safer.

The implementation of TPM may prove to be the best proactive strategic initiative of the organization, enabling them to achieve new benefits, including shaping the organization's success in every area of its operation.

Author Contributions: Conceptualization, M.W. and M.R.; data curation, M.W.; writing—original draft preparation, M.W. and T.G.; writing—review and editing, M.W. and T.G.; visualization, M.W.; supervision, M.R. and L.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Walczak, M. Program doskonalenia konserwacji wyposażenia produkcyjnego TPM. *Zesz. Nauk. Akad. Ekon. Krakowie* **2005**, *670*, 63–75.
2. Beyer, K. Kapitał intelektualny jako podstawa przewagi konkurencyjnej przedsiębiorstw. *Zesz. Nauk. Uniw. Szczecińskiego Stud. I Pr. Wydziału Nauk Ekon. I Zarządzania* **2012**, *25*, 241–254.
3. Kraszewska, M.; Pujer, K. *Konkurencyjność Przedsiębiorstw. Sposoby Budowania Przewagi Konkurencyjnej*, 1st ed.; Exante: Wrocław, Poland, 2017; pp. 16–33.
4. Tajiri, M.; Gotoh, F. *TPM Implementation: A Japanese Approach*, 1st ed.; McGraw-Hill Inc.: New York, NY, USA, 1992.
5. Ahuja, I.P.S.; Khamba, J.S. Total productive maintenance: Literature review and directions. *Int. J. Qual. Reliab. Manag.* **2008**, *25*, 709–756. [CrossRef]
6. Kutucuoglu, K.Y.; Hamali, J.; Irani, Z.; Sharp, J.M. A framework for managing maintenance using performance measurement systems. *Int. J. Oper. Prod. Manag.* **2001**, *21*, 173–194. [CrossRef]
7. Kisiel, P. Koncepcja wdrożenia; wybranych metod Lean Production w przedsiębiorstwie produkcyjnym. *Autobusy Tech. Eksploat. Syst. Transp.* **2017**, *6*, 1410–1414.
8. Ahmed, S.; Hassan, M.H.; Taha, Z. TPM can go beyond maintenance: Excerpt from a case implementation. *J. Qual. Maint. Eng.* **2005**, *11*, 19–42. [CrossRef]
9. Wolska, M.; Folek, A.; Gajda, L.; Roszak, M. Znaczenie wdrożenia metody Total Productive Maintenance w działalności organizacji w obszarach produkcyjnym i pozaprodukcyjnym. In Proceedings of the International Students Scientific Conference Talent Detector, Gliwice, Poland, 26 June 2023.
10. Coetzee, J.L. A holistic approach to the maintenance problem. *J. Qual. Maint. Eng.* **1999**, *5*, 276–280. [CrossRef]
11. Jonsson, P.; Lesshammar, M. Evaluation and improvement of manufacturing performance measurement systems—The role of OEE. *Int. J. Oper. Prod. Manag.* **1999**, *19*, 55–78. [CrossRef]
12. Hardt, F.; Kotyrba, M.; Volna, E.; Jarusek, R. Innovative Approach to Preventive Maintenance of Production Equipment Based on a Modified TPM Methodology for Industry 4.0. *Appl. Sci.* **2021**, *11*, 6953. [CrossRef]
13. Al-Hassan, K.; Chan, J.F.L.; Metcalfe, A.V. The role of total productive maintenance in business excellence. *Total Qual. Manag. Bus. Excell.* **2000**, *11*, S596–S601. [CrossRef]
14. Yoshida, K.; Hongo, E.; Kimura, Y.; Ueno, Y.; Kaneda, M.; Morimoto, T. *Training for TPM: A Manufacturing Success Story*, 1st ed.; Productivity Press: Portland, OR, USA, 1990.
15. Moubray, J. *Reliability Centered Maintenance*, 2nd ed.; Industrial Press: New York, NY, USA, 1997.
16. Maintenance Strategy Review and Development. Available online: https://www.assetintegrityengineering.com/maintenance-reliability/maintenance-strategy-review-development/ (accessed on 10 September 2023).
17. Bảo trì tiên đoán (Predictive Maintenance) là gì? Available online: https://smartindustry.vn/smart-factory/manufacturing-apps/bao-tri-tien-doan-predictive-maintenance-la-gi-3/ (accessed on 10 September 2023).
18. Reactive Maintenance Vs Preventive Maintenance vs. Predictive Maintenance. Available online: https://www.assetinfinity.com/blog/reactive-vs-preventive-vs-predictive (accessed on 10 September 2023).
19. Poór, P.; Ženíšek, D.; Basl, J. Historical Overview of Maintenance Management Strategies: Development from Breakdown Maintenance to Predictive Maintenance in Accordance with Four Industrial Revolutions. In Proceedings of the International Conference on Industrial Engineering and Operations Management, Pilsen, Czech Republic, 23–26 July 2019.
20. Jimeneza, V.J.; Bouhmalaa, N.; Gausdal, A.H. Developing a predictive maintenance model for vessel machinery. *J. Ocean Eng. Sci.* **2020**, *5*, 358–386. [CrossRef]
21. Tchakoua, P.; Wamkeue, R.; Slaoui-Hasnaoui, F.; Tameghe, T.A.; Ekemb, G. New Trends and Future Challenges for Wind Turbines Condition Monitoring. In Proceedings of the 2013 International Conference on Control, Automation and Information Sciences (ICCAIS), Nha Trang City, Vietnam, 25–28 November 2013. [CrossRef]
22. Muhlemann, A.; Oakland, J.; Lockyer, K. *Zarządzanie. Produkcja i Usługi*, 3rd ed.; Wydawnictwo Naukowe PWN: Warszawa, Poland, 2001.
23. Ahuja, I.P.S. Total Productive Maintenance. In *Handbook of Maintenance Management and Engineering*, 1st ed.; Ben-Daya, M., Duffuaa, S.O., Raouf, A., Knezevic, J., Ait-Kadi, D., Eds.; Springer: London, UK, 2009; pp. 417–460. [CrossRef]
24. Nakajima, S. *Introduction to TPM: Total Productive Maintenance*, 11th ed.; Productivity Press Inc.: Portland, OR, USA, 1988.
25. Rhyne, D.M. Total plant performance advantages through total productive maintenance. In Proceedings of the APICS Conference Proceedings, Birmingham, UK, June 1990; pp. 683–686.
26. Wireman, T. *Total Productive Maintenance—An American Approach*, 1st ed.; Industrial Press Inc.: New York, NY, USA, 1992.
27. Robinson, C.J.; Ginder, A.P. *Implementing TPM: The North American Experience*; Productivity Press Inc.: Portland, OR, USA; New York, NY, USA, 1995.
28. McKone, K.E.; Roger, G.S.; Cua, K.O. Total productive maintenance: A contextual view. *J. Oper. Manag.* **1999**, *17*, 123–144. [CrossRef]
29. Chaneski, W.S. Total productive maintenance—An effective technique. *Mod. Mach.* **2002**, *75*, 46–48.

30. History of Japan Institute of Plant maintenance. Available online: https://jipmglobal.com/about/history (accessed on 21 September 2023).
31. Mączyński, W. Profesjonalizm usług Utrzymania Ruchu, czyli TPM. *PB* **2012**, *6*, 54–56.
32. Świtek, S. Analiza poziomu wdrożenia kompleksowego utrzymania ruchu (TPM) na przykładzie firmy z przemysłu elektrotechnicznego. *Zesz. Nauk. Politech. Poznańskiej. Organ. I Zarządzanie* **2017**, *73*, 273–287. [CrossRef]
33. TPM Awards. Available online: https://jipmglobal.com/service/tpm-awards (accessed on 21 September 2023).
34. Heston, T. Culture change for maintenance. *Fabr Met.* **2006**, *5*, 70–72.
35. *IATF 16949*; Quality Management System for Organizations in the Automotive Industry. International Automotive Task Force: Berlin, Germany, 2016.
36. Walczak, M. System utrzymania ruchu czynnikiem przewagi konkurencyjnej przedsiębiorstwa. In *Historia i Perspektywy Nauk o Zarządzaniu*; Mikuła, B., Ed.; Fundacja Uniwersytetu Ekonomicznego w Krakowie: Kraków, Poland, 2012; pp. 411–422.
37. Misiurek, B.; Maśluszczak, Z. Dlaczego w mojej firmie umarł TPM? *Służby Utrzymania Ruchu* **2015**, 42–44. Available online: https://leantrix.com/pl/operator-najlepsza-osoba-do-codziennego-diagnozowania-stanu-maszyny/ (accessed on 1 October 2023).
38. Michlowicz, E.; Karwat, B. Implementation of Total Productive Maintenance—TPM in enterprise. *Sci. J.* **2010**, *24*, 41–47.
39. Operator—Najlepsza Osoba do Codziennego Diagnozowania Stanu Maszyny. Available online: https://leantrix.com/pl/operator-najlepsza-osoba-do-codziennego-diagnozowania-stanu-maszyny/ (accessed on 10 October 2023).
40. Szulc, T. Analiza możliwości wdrożenia koncepcji Total Productive Maintenance (TPM) w organizacjach użyteczności publicznej. *Mechanik* **2015**, *7*, 821–830. [CrossRef]
41. Jain, A.; Singh, R.; Singh, H. Total Productive Maintenance (TPM): A Proposed Model for Indian SMES. *Int. J. Mech. Prod. Eng. Res. Dev.* **2014**, *4*, 1–22.
42. Furman, J. Wdrażanie wybranych narzędzi koncepcji Lean Manufacturing w przedsiębiorstwie produkcyjnym. In *Innowacje w Zarządzaniu i Inżynierii Produkcji*; Knosala, R., Ed.; Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją: Opole, Poland, 2014.
43. Chan, F.T.S.; Lau, H.C.W.; Ip, R.W.L.; Chan, H.K.; Kong, S. Implementation of total productive maintenance: A case study. *Int. J. Prod. Econ.* **2005**, *95*, 71–94. [CrossRef]
44. Komatina, N.; Mačužić, I.; Aleksić, A.; Bergam, T. Determination of barriers priority that impacts to the implementation of the TPM concept by using genetic algorithm. *IETI Trans. Eng. Res. Pract.* **2019**, *3*, 1–19. [CrossRef]
45. Ngoy, K.R.; Israel, K. The Strategy of Successful Total Productive Maintenance (TPM): Implementation and Benefits of TPM (Literature Review). *Int. J. Innov. Res. Eng. Multidiscip. Phys. Sci.* **2021**, *9*, 43–52.
46. Kumar, A. Evolution of Various Losses in Total Productivity Maintenance. *Indian J. Appl. Res.* **2014**, *4*, 155–157. [CrossRef]
47. Braglia, M.; Dallasega, P.; Marrazzini, L. Overall Construction Productivity: A new lean metric to identify construction losses and analyse their causes in Engineer-to-Order construction supply chains. *Prod. Plan. Control* **2022**, *33*, 925–942. [CrossRef]
48. Chikwendu, O.C.; Chima, A.S. Overall Equipment Effectiveness and the Six Big Losses in Total Productive Maintenance. *J. Sci. Eng. Res.* **2018**, *5*, 156–164.
49. *ISO 22400-2*; Automation Systems and Integration. Key Performance Indicators (KPIs) for Manufacturing Operations Management. Part 2: Definitions and Descriptions. ISO: Geneva, Switzerland, 2004.
50. Purba, H.H.; Wijayanto, E.; Aristiara, N. Analysis of Overall Equipment Effectiveness (OEE) with Total Productive Maintenance Method on Jig Cutting: A Case Study in Manufacturing Industry. *Int. J. Sci. Eng. Res.* **2018**, *5*, 397–406.
51. OEE (Overall Equipment Effectiveness). Available online: https://www.leanproduction.com/oee/ (accessed on 30 September 2023).
52. Chlebus, E.; Helman, J.; Rosienkiewicz, M.; Stefaniak, P. Standaryzacja przeprowadzania napraw jako etap wdrożenia Total Productive Maintenance w przemyśle wydobywczym. In *Innowacje w Zarządzaniu i Inżynierii Produkcji*; Knosala, R., Ed.; Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją: Opole, Poland, 2014; pp. 667–677.
53. Nakajima, S. *TPM Development Program: Implementing Total Productive Maintenance*; Productivity Press: Portland, OR, USA, 1989.
54. Naguib, H. A roadmap for the implementation of total productivity maintenance (TPM) in a semiconductor manufacturing operation. In Proceedings of the Semiconductor Manufacturing Science Symposium, ISMSS-1993, IEEE/SEMI International, San Francisco, CA, USA, 19–20 July 1993; pp. 89–97. [CrossRef]
55. Steinbacher, H.R.; Steinbacher, N.L. *TPM for America*; Productivity Press: Portland, OR, USA, 1993.
56. Pirsig, R.M. Total productive maintenance. In *Managing Factory Maintenance*; Levvitt, J., Ed.; Industrial Press Inc.: New York, NY, USA, 1998.
57. Navigating the Path to Total Productive Maintenance (TPM). Available online: https://productivityinc.com/navigating-total-productive-maintenance/ (accessed on 10 October 2023).
58. Total Productive Maintenance: An Overview. Available online: https://www.reliableplant.com/Read/26210/tpm-lean-implement (accessed on 15 September 2023).
59. Poduval, P.S.; Pramod, V.R. Barriers in TPM implementation in industries. *Int. J. Sci. Technol. Res.* **2013**, *2*, 28–33.
60. Singh, M.; Sachdeva, A.; Bhardwaj, A. An interpretive structural modelling approach for analysing barriers in total productive maintenance implementation. *Int. J. Ind. Syst. Eng.* **2014**, *16*, 433–450. [CrossRef]

61. Attri, R.; Grover, S.; Dev, N. A graph theoretic approach to evaluate the intensity of barriers in the implementation of total productive maintenance (TPM). *Int. J. Prod. Res.* **2014**, *52*, 3032–3051. [CrossRef]
62. Rodrigues, M.; Hatakeyama, K. Analysis of the fall of TPM in companies, *J. Mater. Process. Technol.* **2006**, *179*, 276–279. [CrossRef]
63. Hansson, J.; Backlund, F.; Lycke, L. Managing Commitment: Increasing the Odds for Successful Implementation of TQM, TPM or RCM. *Int. J. Qual. Reliab. Manag.* **2003**, *20*, 993–1008. [CrossRef]
64. Bohoris, G.A.; Vamvalis, C.; Tracey, W.; Ignatiadou, K. TPM Implementation in Land-Rover with Assistance of a CMMS. *J. Qual. Maint. Eng.* **1995**, *1*, 3–16. [CrossRef]
65. Wu, B.; Seddon, J.J. An anthropocentric approach to knowledge-based preventive maintenance. *J. Intell. Manuf.* **1994**, *5*, 389–397. [CrossRef]
66. Lycke, L.; Akersten, P.A. Experiences of Implementing TPM in Swedish Industries. *Int. J. Reliab. Appl.* **2000**, *1*, 1–14.
67. Parida, A.; Kumar, U. Maintenance Performance Measurement: Issues and Challenges. *J. Qual. Maint. Eng.* **2006**, *12*, 239–251. [CrossRef]
68. Groote, P.D. Maintenance Performance Analysis: A Practical Approach. *J. Qual. Maint. Eng.* **1995**, *1*, 4–24. [CrossRef]
69. Hutchins, D. Introducing TPM. *Manuf. Eng.* **1998**, *77*, 34–37. [CrossRef]
70. McKone, K.E.; Roger, G.S.; Cua, K.O. The Impact of Total Productive Maintenance Practices on Manufacturing Performance. *J. Oper. Manag.* **2001**, *19*, 39–58. [CrossRef]
71. Ahuja, I.P.S.; Khamba, J.S. Strategies and Success Factors for Overcoming Challenges in TPM Implementation in Indian Manufacturing Industry. *J. Qual. Maint. Eng.* **2008**, *14*, 123–147. [CrossRef]
72. Fredendall, L.D.; Patterson, J.W.; Kennedy, W.J.; Griffin, T. Maintenance Modeling, its Strategic Impact. *J. Manag. Issues* **1997**, *9*, 440–453.
73. Wayne, P.J.; Kennedy, W.J.; Fredendall, F.D. Total Productive Maintenance Is Not for This Company. *Prod. Inventory Manag. J.* **1995**, *36*, 61–63.
74. Katila, P. *Applying Total Productive Maintenance-TPM Principles in the Flexible Manufacturing Systems*; Technical Report; Lulea Tekniska University: Norrbotten County, Sweden, 2000; pp. 21–25.
75. Windle, W.M. TPM: More alphabet soup or a useful plant improvement concept? *Plant. Eng.-Chic.* **1993**, *47*, 62–64.
76. Chand, G.; Shirvani, B. Implementation of TPM in cellular manufacture. *J. Mater. Process. Technol.* **2000**, *103*, 149–154. [CrossRef]
77. Blanchard, B.S. An Advance Approach for Implementing TPM in Manufacturing Environment. *J. Qual. Maint. Eng.* **1997**, *5*, 162–181.
78. Total Productive Maintenance. Improve Equipment Performance and Reliability. Available online: https://www.bradyid.com/applications/lean-visual-workplace/lean-visual-workplace-tpm (accessed on 3 January 2023).
79. Wolska, M.; Folek, A.; Gorewoda, T.; Gajda, L.; Roszak, M. Wstępna ocena potencjału metody Total Productive Maintenance w działalności laboratorium badawczego. In Proceedings of the International Students Scientific Conference Talent Detector, Gliwice, Poland, 27 January 2023.
80. Arivalagan, A.; Kasi Viswanathan, K.S.; Sudhakar, B. "TPM"—A Philosophy for Further Enhancement of Performance. *IPPTA* **2003**, *15*, 57–60.
81. Ireland, F.; Dale, B.G. A study of total productive maintenance implementation. *J. Qual. Maint. Eng.* **2001**, *7*, 183–192. [CrossRef]
82. Lawrence, J.J. Use of mathematical modeling to give your TPM implementation effort an extra boost. *J. Qual. Maint. Eng.* **1999**, *5*, 62–69. [CrossRef]
83. Albert, H.C.; Chan, P.K. TPM implementation in China: A case study. *Int. J. Qual. Reliab. Manag.* **2000**, *17*, 144–157.
84. Dogra, M.; Sharma, V.S.; Sachdeva, A.; Dureja, J.S. TPM: A Key Strategy for Productivity Improvement in Process Industry. *J. Eng. Sci. Technol.* **2011**, *6*, 1–16.
85. Kumar, P.; Varambally, K.V.M.; Rodrigues, L.L. A Methodology for Implementing Total Productive Maintenance in Manufacturing Industries—A Case Study. *Int. J. Eng. Res. Dev.* **2012**, *5*, 32–39.
86. Iftekhar, A.; Sazedul, K.; Mosharraf, H. Effective Implementation of Total Productive Maintenance and Its Impacts on Breakdown, Repair and Setup Time. In Proceedings of the Global Engineering, Science and Technology Conference, Dhaka, Bangladesh, 28–29 December 2012.
87. TPM: Case Study. Available online: https://www.productivityinc.com/manufacturing-industry/total-productive-maintenance-tpm/ (accessed on 28 July 2023).
88. Haddad, T.H.; Jaaron, A.A. The applicability of total productive maintenance for healthcare facilities: An implementation methodology. *IJBHT* **2012**, *2*, 148–155.
89. Chompu-Inwai, R.; Tipgunta, S.; Sunawan, A. Implementation of total productive maintenance in healthcare: A pilot study. In Proceedings of the International Conference on Service Systems and Service Management, Melbourne, VIC, Australia, 29 June–2 July 2008.
90. Ali, A.Y. Application of Total Productive Maintenance in Service Organization. *Int. J. Res. Ind. Eng.* **2019**, *8*, 176–186.
91. Valamede, L.S.; Santos Akkari, A.C. Lean 4.0: A New Holistic Approach for the Integration of Lean Manufacturing Tools and Digital Technologies. *Int. J. Math. Eng. Manag. Sci.* **2020**, *5*, 851–868. [CrossRef]

92. Total Productive Maintenance and Industry 4.0. Available online: https://www.maintwiz.com/blog/total-productive-maintenance-guide/#9_The_Future_of_Total_Productive_Maintenance (accessed on 25 November 2023).
93. Hallioui, A.; Herrou, B.; Katina, P.F.; Santos, R.S.; Egbue, O.; Jasiulewicz-Kaczmarek, M.; Soares, J.M.; Carmona Marques, P. A Review of Sustainable Total Productive Maintenance (STPM). *Sustainability* **2023**, *15*, 12362. [CrossRef]