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Research article

Literature Review on the Relationship between Total Productive Maintenance (TPM), Lean Maintenance, and Healthcare Systems' Sustainable Performances

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A B S T R A C T

This paper explores theoretical and practical foundations for integrating Total Productive Maintenance (TPM) and lean maintenance to achieve healthcare systems' sustainable performances. A systematic literature review is performed. The review methodology consists of seven steps: defining the research question, searching the literature, screening the literature, documenting the search results, assessing articles' quality, documenting the review results, and synthesizing. The search found a limited number of publications exploring the relationship between TPM and lean maintenance to achieve sustainable performances of healthcare systems. Most contributors were from developing countries. The publication peaked in 2023 and 2024, and the number tended to rise from 2012 to 2024. The synthesis process shows limited evidence about the relationship between TPM and hospital sustainable performance. Theoretically, the relationship between TPM, lean maintenance, and sustainable performance in healthcare systems is plausible. However, the concepts were rarely tested. For future research, this paper proposes to investigate the relationship between TPM practices and hospitals' sustainable performance moderated by lean maintenance. A conceptual model is also presented.

1. Introduction

In a competitive business environment, a company's effort to improve operational efficiency and reduce cost is essential to survive. Governments also force industries to control their environmental impacts and comply with environmental regulations. Thus, industries must be able to identify and control their environmental impacts and manage risks and opportunities.

Previously seen as a cost center activity, maintenance activity is now recognized as a strategic contributor to improve efficiency, reduce costs, and meet the environmental and social

responsibilities of the industries. Maintenance activity evolved from the corrective, reactive, and preventive approach to an integrated approach involving all business aspects. Two strategies are widely used in the industry for an integrated maintenance approach: Total Productive Maintenance (TPM) and lean maintenance [1].

TPM is a maintenance approach that maximizes overall equipment effectiveness by involving all stakeholders within a company, from operators to the company's leadership. TPM focuses on preventive maintenance, autonomous maintenance, continuous improvement, and training to achieve zero breakdowns, defects, and accidents.

On the other hand, lean maintenance evolved from lean manufacturing. Lean maintenance focuses on eliminating waste and non-value-added activities and streamlining the process. Integrating TPM and lean maintenance can produce more efficient, reliable, and responsive maintenance systems [2], [3].

Furthermore, maintenance activity is also critical in sustainability. Maintenance can contribute to energy consumption reduction, emission minimization, extend equipment life, and provide a safe working environment. Therefore, integrating TPM and lean maintenance with the industry's sustainable performance is vital because industries are under constant pressure to implement sustainable practices [4]. When implemented correctly, the integration supports the triple bottom line: economic, environmental, and social performance.

Although, integrating the three concepts is beneficial, there are limited frameworks and evidence on how the three concepts must be implemented. Previous studies tended to isolate and address the concepts individually but did not explore the intersection among them [5].

The healthcare sector is among the sectors whose implementation of TPM, lean maintenance, or sustainable performance is limited. Theoretically, the implementation of the above three concepts can lead to improvement in patient care and safety. However, the healthcare system is unique compared to the manufacturing systems.

The system's primary objective is to preserve human life. The system is highly variable because each patient has a unique condition that may require different responses or treatments. Furthermore, the healthcare system has diverse stakeholders and is subject to ethical, legal, and regulatory scrutiny. The manufacturing systems are also regulated but do not have the same level of moral complexity.

Therefore, while the healthcare systems can adopt the implementation of TPM and lean maintenance from the manufacturing system, the application must be carefully adapted. The variability,

criticality, and human-centered nature of healthcare require a more flexible, ethical, and patient-focused approach than traditional manufacturing systems. Thus, research is needed to investigate the synergies among the three concepts to achieve sustainable maintenance performance in the healthcare systems.

This paper aims to fill this gap. The paper will explore the theoretical and practical foundations for integrating TPM and lean maintenance to achieve sustainable performance in healthcare systems. By conducting a literature review, this research aims to propose a conceptual model on how TPM and lean maintenance affect a healthcare system's sustainable performance.

2. Method

This paper followed Vicentin et al. [4] and. Vicente et al. [6] in conducting the literature review. There were seven steps in conducting the review. They are defining the research question, searching the literature, screening the literature, documenting the search results, assessing articles' quality, documenting the review results, and synthesizing. The step-by-step procedure is presented in Figure 1.

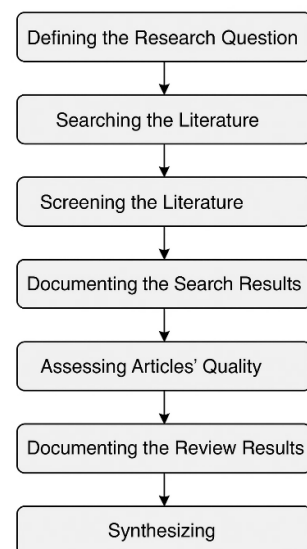


Figure 1. Literature review step-by-step procedure

Defining the research question

The review's objective is to find the state of the art on how TPM practice affects the sustainable performance of a hospital mediated by lean maintenance. The TPM practice is the dependent

variable, a hospital's sustainable performance is the independent variable, and lean maintenance is the mediating variable. Thus, the research question in this review is, "According to the literature, is there a relationship between TPM practice and a hospital's sustainable performance if they are mediated by lean maintenance?"

Searching the literature

The search involved determining the databases included, defining the combination of keywords, and searching the literature in the databases using the combinations of keywords. In this paper, the databases included were Scopus and Google Scholar.

The reasons for choosing Scopus were that it is a curated database, provides citation analysis, allows precise filtering, makes it easier to find relevant and credible articles, and has consistent metadata. Google Scholar was selected because it has wide coverage, free and early access, and is quick and simple.

The literature in the database was searched by using the following combinations of keywords: "Total Productive Maintenance" AND "Lean Maintenance," "Total Productive Maintenance" AND "Hospital Sustainable Performance," "Lean Maintenance" AND "Hospital Sustainable Performance," and "Total Productive Maintenance" AND "Lean Maintenance" AND "Hospital Sustainable Performance." The AND operator means the search contains both or all three keywords. The AND operators were used because the review's objective is to see what the literature said about the relationship between TPM practice and a hospital's sustainable performance if they are moderated by lean maintenance.

Screening the literature

Not all articles suggested by the databases were reviewed. This research used the following criteria to include an article:

1. The articles were published in journals, and

2. The articles suited the research question according to their titles and abstracts.

This step also involved eliminating duplications found in the search results. No exclusion was made regarding the years of publication. The reason is that the area combining TPM, lean maintenance, and sustainability is relatively new.

Documenting the search results

After screening the search results, the articles were documented using Mendeley. The reasons for choosing Mendeley were that it automatically organizes the articles, can import references from Scopus and Google Scholar, can generate citations in various styles, allows highlighting, and suggests relevant articles based on the library created.

Assessing articles' quality and documenting the review results

This assessment included evaluating an article's references, relevance, authors' reputation, journal reputation, and publisher reputation. An article might be excluded after being assessed. The contents of the included articles were then documented in a table format.

Synthesizing

In this step, the findings' advantages, disadvantages, and meaning were stated. The direction for future research was suggested.

3. Results and Discussion

Figure 2 presents the results of the search procedure. By using the keywords combinations of "Total Productive Maintenance" AND "Lean Maintenance," "Total Productive Maintenance" AND "Hospital Sustainable Performance," "Lean Maintenance" AND "Hospital Sustainable Performance," and "Total Productive Maintenance" AND "Lean Maintenance" AND "Hospital Sustainable Performance" to search the literature in the Scopus and Google Scholar databases, not many articles were found. The limited number of articles means that the researchers have not explored the

integration of TPM and lean maintenance to achieve sustainable performance.

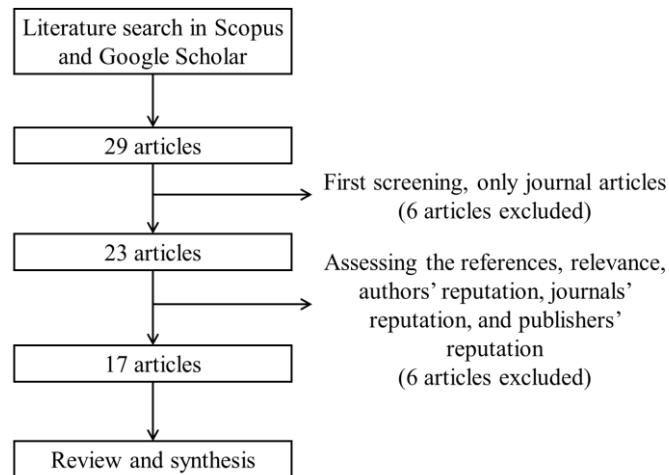


Figure 2. Results of search procedure

After conducting the first screening or eliminating non-journal articles, 23 publications were left. Furthermore, six more articles were excluded after assessing the references, relevance, authors, journals, and publishers, and 17 publications were reviewed and synthesized.

The results show that the countries of origin of the authors whose articles were considered in this review are mainly developing countries such as India and Indonesia. Authors whose countries of origin are developed countries are about 30% and distributed in the UK, USA, Australia, Portugal, Poland, and Italy. Table 1 presents the authors' countries of origin whose articles are considered in this review.

Sustainability dominates the journals that publish the articles. Other journals shared the same percentage of articles, Table 2. Regarding publishers, Emerald, MDPI, and Elsevier are among the top on the list. Other well-known publishers include Wiley and Springer. The rest are not famous publishers. Figure 3 presents the distribution of articles' publishers considered in this review.

Table 1. Authors' countries of origin distribution

Country	Percentage
Indonesia	23%
India	22%
UK	10%
Malaysia	8%
Australia	7%
Portugal	7%
Poland	5%
Chile	3%
Iraq	3%
Morocco	3%
Palestine	3%
Egypt	2%
Italy	2%
USA	2%
Total	100%

Some literature published between 2014 and 2025 tended to isolate the issues of TPM, lean maintenance, and its application in healthcare systems separately. They focused on the importance of equipment, maintenance, the benefits of TPM, and the challenges of applying TPM in a healthcare system.

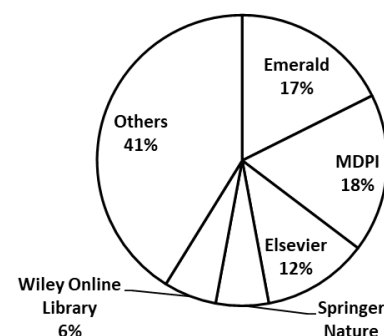


Figure 3. Publishers' distribution

Table 2. Journals distribution

Country	Percentage
Sustainability	12%
Journal of Remanufacturing	6%
Procedia Manufacturing	6%
Benchmarking: An International Journal	6%
The International Journal of Logistics Management	6%
IFAC-PapersOnLine	6%
Energies	6%
Others	53%
Total	100%

Figure 4 presents the number of publications integrating TPM, lean maintenance, and sustainable performance. The number of publications tends to increase, peaking in 2023 and 2024. The number of publications in 2025 is limited because it is the running year. In the peak years, the publications focused on using industry 4.0 technologies in TPM and their roles in improving business sustainability performances [7], [8].

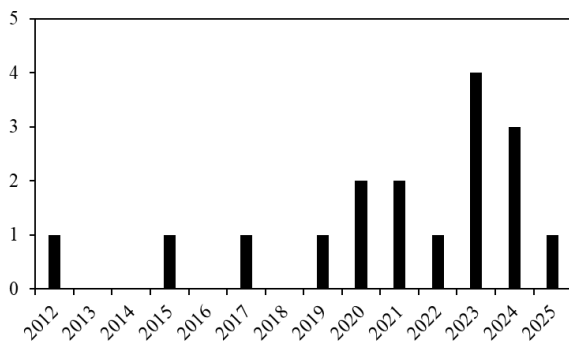


Figure 4. Number of publications from 2012 to 2025

Based on the results of the synthesis step, hospitals rely heavily on advanced medical equipment, such as diagnostic machines, life-support systems, and imaging devices, to provide high-quality care. The failure of such equipment can lead to delayed diagnoses, compromised patient care, and increased operational costs. As healthcare systems face rising demands and tighter budgets, effective medical equipment maintenance is essential to ensure hospital services' continuous availability and reliability [9]. In this context, implementing TPM in hospitals offers a promising approach to enhancing equipment reliability and reducing operational disruptions [10].

However, the implementation faced unique challenges that differ from those in manufacturing

industries. These included the complexity and variety of equipment, the need for highly specialized skills to repair and maintain medical devices, and strict regulatory standards [11]. In addition, many hospitals struggled with a lack of standardized maintenance procedures, leading to inefficient use of resources and increased downtime. Consequently, there is a growing interest in adopting TPM's structured, preventive approach to maintenance in the healthcare sector.

Literature also highlighted that the implementation of TPM in a hospital setting requires significant adaptation of traditional methods used in manufacturing. In hospitals, the focus is not only on the equipment itself but also on the impact of downtime on patient care, staff workflows, and operational efficiency. According to Haddad and Jaroon [12], the following principles of TPM can be effectively integrated into hospital maintenance systems:

Autonomous Maintenance (AM) - One of the most critical aspects of TPM is empowering frontline workers, such as nurses and medical technicians, to take ownership of basic equipment maintenance tasks. In hospitals, this can involve training staff to perform routine checks on medical devices, such as verifying calibration, ensuring cleanliness, and conducting minor troubleshooting. By doing so, the risk of equipment failure can be minimized, and the burden on dedicated maintenance personnel can be reduced.

Planned Maintenance (PM) - Preventive maintenance is essential in the healthcare sector due to the high risk of life-threatening consequences when medical equipment fails. Planned hospital maintenance involves scheduling regular maintenance activities to prevent unscheduled downtime, including inspections, software updates, and repairs. By moving from a reactive to a proactive maintenance model, hospitals can reduce emergency repairs, which are typically costly and disruptive.

Focused Improvement (FI) - Improvements in hospitals involve identifying recurring issues with

equipment performance, analyzing their root causes, and implementing targeted interventions. This approach not only improves equipment reliability but also enhances the overall efficiency of hospital operations by reducing delays and optimizing the use of resources.

Training and Education - For TPM to be successful, hospital staff must be adequately trained in the principles and techniques of TPM. Regular training on maintenance best practices and the importance of equipment upkeep is essential for cultivating a culture of shared responsibility for hospital equipment. Educating both clinical and non-clinical staff on TPM's benefits can help overcome resistance to change.

Safety and Compliance - Healthcare settings are subject to stringent safety regulations, making integrating TPM's safety and health pillar particularly relevant. Proper equipment maintenance ensures compliance with safety standards, reduces the risk of medical errors, and fosters a safe working environment for staff and patients.

Literature also highlighted the benefits of TPM implementation in healthcare systems. The first benefit is that TPM improves equipment availability. By emphasizing preventive maintenance and operator involvement, TPM ensures that medical equipment functions optimally, reducing the chances of unexpected breakdowns and improving equipment availability [13], [14]. Second, TPM enhances patient care. Patient care improves with fewer equipment failures and shorter downtime as diagnostic and treatment processes are more consistent and reliable. Moreover, TPM can lead to quicker device recovery times, minimizing the impact on patient services. Third, TPM reduces costs. TPM's emphasis on planned maintenance and early problem identification leads to cost savings by reducing emergency repair expenses and extending the lifespan of medical devices. Hospitals also benefit from better resource allocation, as the maintenance team can focus on critical issues while operators take care of basic tasks [13], [15]. Fourth, TPM

empowers and engages staff. The involvement of hospital staff in maintenance activities fosters a culture of ownership and responsibility. The involvement can lead to better collaboration between departments, improved morale, and enhanced operational efficiency [16].

After 2020, the literature started to explore the relationship between TPM, lean maintenance, and hospital sustainability performance. The literature can be grouped into TPM, lean maintenance and industry 4.0, and healthcare maintenance and sustainable performance.

The first group was mainly in the area of manufacturing. The focus was on improving equipment efficiency and its relationship with lean maintenance [17], [18], [19].

The second group focused on improving the efficiency of maintenance activity, and the application was mainly in the manufacturing area. The efficiency was improved by optimizing the maintenance planning with the help of optimization techniques, automation, and digitalization [7], [8].

For the third group, the literature explored the integration of lean and green practices [20], the use of industry 4.0 technologies for sustainable manufacturing, and the benefit of lean management practices on economic sustainability. The applications were in the manufacturing and service sectors. The implementation in the healthcare systems is limited. Studies by Khalil and Foo [21] applied a lean approach to improving medicine management for a hospital in Australia.

Studies also revealed the benefits of TPM to sustainability. TPM can improve sustainability's environmental, social, and economic dimensions [17]. The authors investigated the relationship between TPM practices and sustainability performance using the resource-based view (RBV). The integration of TPM with Industry 4.0, moderated by circular economy practices, positively impacted sustainable manufacturing outcomes [7]. Furthermore, blockchain and circular economy principles supported TPM in enhancing

operational efficiency and sustainability in smart manufacturing environments [8]. A review of the new concept called Sustainable TPM (STPM) can be found in [18]. The review explored the strategic role of TPM in improving sustainability across various industries.

There was limited literature on developing a framework for integrating TPM and lean maintenance to achieve sustainable performance. A study by [20] showed strong connections between lean and green practices with the triple bottom line concept: people, planet, and profit. A framework for integrating Maintenance 4.0 technologies to achieve sustainable maintenance practices, highlighting predictive maintenance, IoT, and data analytics, was developed by Jasiulewicz-Kaczmarek and Gola [22].

The above discussion indicated that the majority of the study was in the manufacturing area. Implementing lean improvement in the healthcare system was mainly to improve the medication inventory management system [21]. Implementing TPM and lean maintenance to achieve sustainable hospital performance was limited.

Based on the above discussion, it is concluded that TPM and lean maintenance were well-represented by journal articles demonstrating real-world applications in various industries but not in the healthcare sector. Hospital sustainable performance in maintenance systems, at least within structured, peer-reviewed journal literature from 2020 onward, appears less developed. Thus, the following relationships were inferred from the literature, Table 3.

Table 3. Concepts relationship

Concept	Relationship	Literature Support
TPM → Lean Maintenance	Strong direct relationship	[18], [19] — TPM supports Lean via equipment reliability, 5S, and work standard.
Lean Maintenance → Sustainability	Well-established	[16], [18] — Lean reduces waste, downtime, energy, and cost.

TPM → Hospital Sustainable Performance	Theoretical/limited evidence	Conceptual models suggest TPM supports quality, safety, and efficiency in healthcare (but few empirical hospital-based studies).
TPM → Lean → Sustainable Hospital	Plausible & Supported in Industry	Though rarely tested in hospitals, models from manufacturing (e.g. [18]) show TPM supports Lean which in turn boosts sustainability.

While no direct literature study from 2010–2025 shows TPM → Lean → Hospital Sustainability empirically, the framework is highly applicable, and studies in manufacturing strongly support this causal chain. Therefore, it is a valid basis for a hypothesis in a research paper, a conceptual framework for a healthcare case study, and designing an intervention model for sustainable hospital maintenance.

Thus, for future research, this paper proposes to test the relationship between TPM practices (X) and hospital sustainable performance (Y) moderated by lean maintenance (Z). The manifest variables under X will include staff involvement, discipline, maintenance, information tracking, and housekeeping. The manifest variables under Y will be the hospital's environment, economic, and social performance. At the same time, the manifest variables under Z are unproductive work, delays, unnecessary activities, poor inventory management, and underutilization of machinery and people. The conceptual model is presented in Figure 5.

The relationship between the three variables can be observed by conducting a survey on a hospitals' population. A questionnaire must be well developed and the results are analyzed using multivariate statistics. Based on the statistical analysis, a framework to integrate TPM and lean maintenance to achieve hospital sustainable performance can be developed.

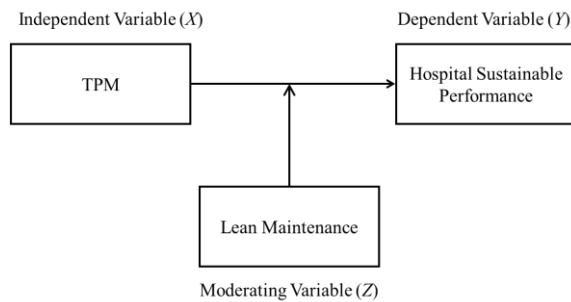


Figure 5. Conceptual model for future research

4. Conclusion

This paper conducted a literature review to find the state of the art regarding integrating TPM practices, lean maintenance, and hospitals' sustainable performances. The search was done using Scopus and Google Scholar databases. Combinations of keywords, such as total productive maintenance, lean maintenance, and sustainable performance, and a two-level screening process were used. The first screening included journal articles only and suited the research question in this paper. The second screening assessed the article's references, relevance, authors, journal, and publisher reputation.

The search found a limited number of journal articles exploring the relationship between TPM, lean maintenance, and sustainable performance of healthcare systems. Most contributors were from developing countries, and the publication peaked in 2023 and 2024. The number of publications tended to rise from 2012 to 2024.

The synthesis process found a strong relationship between TPM and lean maintenance. TPM supports lean via equipment reliability 5S and work standards. The relationship between lean maintenance and sustainability is well-established. Lean practices reduce waste, downtime, energy, and cost.

However, there is limited evidence regarding the relationship between TPM and hospital sustainable performance. Conceptual models suggest TPM supports quality, safety, and efficiency in healthcare, but only a few empirical hospital-based studies are available. Moreover, the literature showed that the relationship between TPM, lean

maintenance, and hospital sustainable performance is plausible. Though rarely tested in hospitals, models from manufacturing show TPM supports Lean, which boosts sustainability.

Thus, for future research, this paper proposes an investigation of the relationship between TPM practices (X) and hospital sustainable performance (Y) moderated by lean maintenance (Z). The relationship between the three variables can be observed by surveying a population of hospitals. A framework to integrate TPM and lean maintenance to achieve sustainable performances in hospitals can be developed based on the relationship suggested by the statistical model.

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