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Lean and TRIZ for improving the maintenance process

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Abstract. Maintenance plays an essential role in the progress of an organization. In order to achieve excellent performance, maintenance strategies must be linked to manufacturing strategies such as Lean. Based on the available data, this paper provides an understanding of the existing research related to the use of Lean and TRIZ within the maintenance process. In order to identify the need for further research in this area. The objective of this paper is then to answer the following question: How can Lean and TRIZ improve the maintenance process? To do this, we focus mainly on the analysis of previous work where TRIZ tools or Lean manufacturing methods have been used individually to improve the maintenance process. The results of previous studies were analyzed and then the main problems that were detected in the previous literature were identified.

Keywords: Lean manufacturing, maintenance, TRIZ, Lean maintenance, process.

1 Introduction

Industrial maintenance plays an increasingly important role in the productivity of a company. As a result, companies can no longer neglect the maintenance of their production tools and maintenance is considered a source of optimization and even a profit factor.

On the other hand, the environment in which companies operate is constantly changing. Between more intense competition and increasingly demanding customers, knowing how to adapt quickly and improve is the key to producing better results. This is where Lean Management comes into play to ensure the sustainability of the company. This approach proposes a structured problem-solving approach to improve industrial performance in the long term. Its main strength is not to solve problems, but to recognize them [1].

On the other hand, there are more sophisticated methods for better and more innovative solutions. Innovative solutions can be found by using systematic creativity tools called TRIZ (Theory of Inventive Problem Solving).

Indeed, this article addresses the question of how Lean and TRIZ have been used to improve the maintenance process. This study conducted a literature review. The review was conducted to identify and understand the existing literature on Lean maintenance and TRIZ in maintenance and to evaluate the contributions and summarize the knowledge, thereby identifying potential directions for future research. Major electronic databases were explored to gather literature on the integration of Lean and TRIZ in maintenance. A total of 31 related articles published between 2000 and 2022 were included in this study. This study is organized as follows. Section 2 demonstrates the methodology of the proposed research. Section 3 presents the research results: it gives an overview of the application of Lean and TRIZ concepts in maintenance and their developments in the literature. Section 4 concludes the study with some directions for future research.

2 Methodology

In order to achieve the research objectives and to answer the question of how TRIZ and Lean have been used individually as a means of improving maintenance process activities, a literature review was conducted.

The work of other authors provided the raw information for the research, forming the list of materials to be analyzed. However, no research process can cover the entire knowledge because documents such as theses and dissertations are difficult to collect. Therefore, knowledge integrators have to work within the limits of time and material type [2]. This study is characterized by a consultation of previous works indexed in the various scientific databases. The focus was on using the resources of the Web of Science and Scopus databases. Because there were not many publications on this topic, other research sources were included. Sources such as Google Scholar, Research gate, TRIZ Journal, direct sciences etc. Articles published between 2000 and 2022 were retrieved using the following keywords: "Lean", "maintenance", "Lean maintenance", "TRIZ" and "TRIZ and maintenance", "Lean & TRIZ".

Table 1. Research keywords.

Time period considered	Search engines used	keywords
2000-2022	Taylor & Francis, Emerald, IEEE, Inderscience, Sage, Science Direct, and Springer Link	Lean maintenance /Lean TPM / Lean Tools AND TPM TRIZ AND maintenance/ TRIZ IN maintenance /Lean AND TRIZ AND maintenance

The publications found were studied and conclusions were drawn. The review process is illustrated in the following figure:

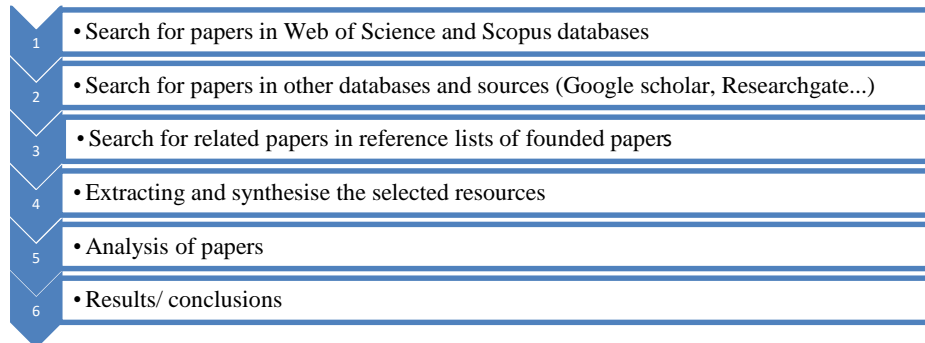


Fig. 1. Flowchart of the literature review procedure.

3 Research findings :

This section presents the results obtained from searches of different databases, followed by a discussion and final remarks. For a better understanding, these publications can be divided into two groups. Firstly, publications that focus on the integration of Lean concepts in the maintenance function. The second group includes publications that focus on the use of TRIZ concepts to improve maintenance activities.

3.1 Lean and maintenance

The integration of lean thinking into maintenance is known as lean maintenance (LM). Smith [3] defined lean maintenance as "a proactive maintenance operation employing planned and scheduled maintenance activities through Total Productive Maintenance (TPM) practices using maintenance strategies developed through the application of Reliability Centered Maintenance (RCM) decision logic and practiced by autonomous (self-directed) action teams".

Lean Maintenance is a combination of Lean and Maintenance, combining their respective approaches, methods and tools. So if Lean is more concerned with the speed of the process and anything that might slow it down, then Maintenance is essentially concerned with keeping the asset in a state that allows it to perform the functions it needs to perform and ensures its availability for production [4].

Lean Maintenance contributes to providing better quality and low cost products in the shortest possible time [5]. Lean Maintenance (LM) improves organizational profitability by identifying and eliminating maintenance-related waste [6].

Lean maintenance perspective. One of the main steps in improving maintenance processes is to develop a system to identify VA (Value Added) and NVA (Non-Value Added) activities and to recognize waste types [7]. To do this, Lean maintenance includes several tools and methods, such as:

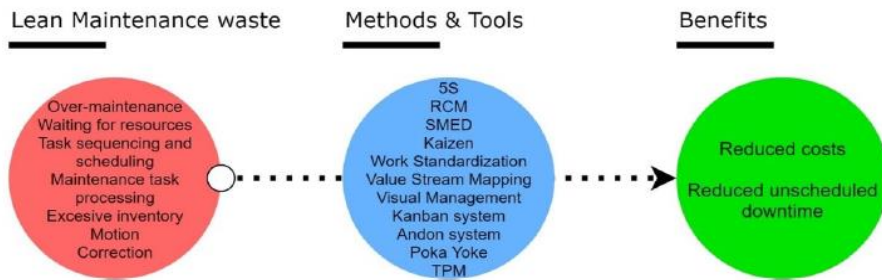


Fig. 2. Lean maintenance perspective

- 5S: as production, the aim of 5S is to eliminate clutter, tidy up tools, clean the workshop and thus keep workstations tidy. They are essential to the introduction of Lean maintenance.
- Value Stream Mapping: VSM is a necessary tool at the beginning of the Lean maintenance implementation.
- Standard work: It aims to standardize the best way to carry out an operation, task or activity.
- SMED: (Single minute exchange of die) is a time analysis and reduction method. Minimize downtime for planned maintenance.
- Kanban: Kanban, i.e. cards, Task Scheduling allows for a graphical representation of tasks and maintenance operations in proportion to their priority and duration
- Kaizen: Kaizen can be used for reliability improvement.
- Jidoka: Maintenance must respect the Jidoka philosophy, which postulates that quality must be constructed a priori.
- Just In Time (JIT): Spare parts and materials are used at the time of need to avoid unnecessary stocks and thus reduce storage costs.

Development of LM in the literature. The LM studies examined are dated from 2000 to 2022 with the total number of 20 retrievable publications as shown in the figure below.

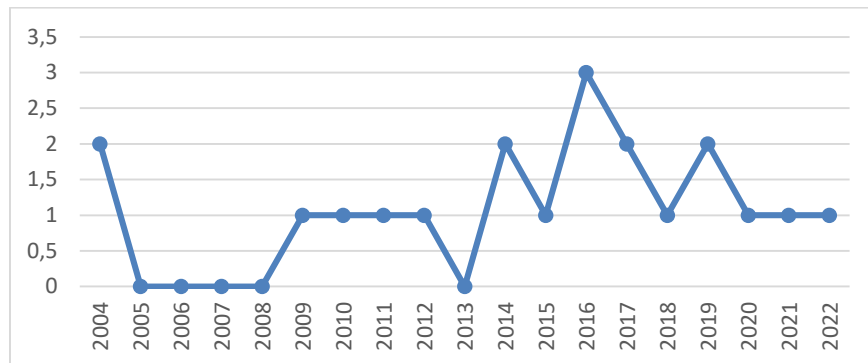


Fig. 3. Numbers of publications in years

From 2000 to 2022, the publications reviewed were aimed at the integration of Lean into the maintenance process and focused on three aspects, namely the LM implementation initiative, the analysis of Lean maintenance challenges and the development of methods to measure the level of implementation of Lean in maintenance. The objectives of each publication are presented in the table below.

Table 2. Review of existing literature on lean maintenance.

References	Year	Contribution
1- [3] 2-[8]	2004	1-Definition of Lean Maintenance. Discussion of the elements of successful Lean maintenance. 2-Development of a fleet repair and maintenance model based on Lean principles and current best practices.
[9]	2009	Determination of the main factors and parameters of maintenance operations that are most effective in improving production towards a Lean system.
[10]	2010	Formulation of a model that not only determines the minimum level of maintenance requirements, but also meets the expected level of reliability.
[11]	2011	Provide an overview of the state of the art of Lean in the aviation MRO industry.
[12]	2012	Analyze the challenges of Lean Maintenance to assess its impact on Lean Maintenance.
[13]	2014	Present a questionnaire survey on the application of Lean engineering principles and tools in a maintenance context in the Swedish industry.
[14]	2014	Optimization of maintenance of industrial systems by using Lean six Sigma bases
[15]	2015	propose a scheme for the integration of lean management in the maintenance process
1-[16]	2016	1-proposed an integration between the Tompkins audit as a ME assessment tool and the technical reverse-AMDEC as a relatively new LM tool in addition to the

2- [17]		traditional PDCA cycle: study the effect of this model through a case study.
3- [18]		2-development of a process to identify the resources needed for maintenance before the modularization of maintenance tasks and resources can take place. Lean is identified as an important first step before the modularization of maintenance tasks. 3- Proposal of a method to measure the level of implementation of Lean in the aviation MRO industry.
[19]	2017	2-presentation of the experience gathered in two projects of Lean maintenance in thermoelectric power plants.
[20]	2018	Identification of the different types of maintenance losses evident in the companies and how the identified maintenance losses are reduced or eliminated by Lean tools.
[21]	2019	1-Implementation of Lean methodologies in the management of consumables in the maintenance workshops of an industrial company.
[22]		2-proposal of a new approach : Lean maintenance based on the principles and tools of Lean manufacturing
[23]	2020	Definition of a clearer scene of the implementation of the Lean philosophy in maintenance and sustainability from an empirical point of view based on two case studies.
[24]	2021	1-Development of a decision support system to select the appropriate Lean maintenance methods and tools that have the greatest impact on the company's operational results.
[25]	2022	Introduction of a framework to integrate sustainability criteria and develop sustainable TPM (Sus-TPM) as a complement to TPM practices.

3.2 TRIZ

TRIZ (Russian acronym for Theory of Inventive Problem Solving) is a heuristic approach to solving innovation problems, mainly technical. It was developed from 1946 by the Soviet engineer Genrich Altshuller [26]. TRIZ is a science that not only identifies and solves creative problems in each field of knowledge, but also develops creative (inventive) thinking and develops the characteristics of the creative personality [27]. TRIZ leads the user to a generic and abstract formulation of his problem, and then to principles of solving the abstract problem intended to inspire inventive solutions in the real problem space. TRIZ is based on the analysis of 40,000 patents selected from 400,000 international patents. Altshuller and his team derived some basic regularities and patterns that governed the processes of problem solving, new idea creation and

innovation. They have the characteristic of presenting common principles of innovation, and this in very varied domains[28].TRIZ was originally developed for technical problems. However, it has found applications in various other fields.

Development of TRIZ in maintenance. The studies reviewed are dated from 2000 to 2022 with the total number of 11 retrievable publications as shown in the figure below.

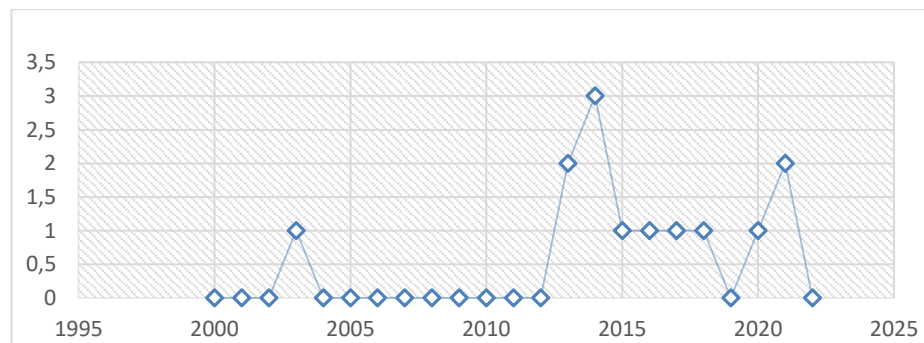


Fig. 4.Number of publications

Indeed, the association of TRIZ with maintenance activities is not new. In 2003, in [29] the authors applied TRIZ methodology to solve a maintenance problem for a drinking yoghurt production system. The application of TRIZ provides both insight into how best to define the problem, and then allows for the development of potential solutions that can be used both to solve the maintenance problem and to prevent system failure. Then, in 2013 the RCA root cause analysis for identifying causes of failure is combined with TRIZ to guide the search for effective solutions [30]. The use of RCA-TRIZ allows critical defects to be found and solutions to be generated, with a lower risk of failure than using trial and error methods. Similarly in [31] TRIZ was applied to maintainability design to create a set of innovative TRIZ-based approaches to solving maintenance problems. Then in 2014, in [32] The effectiveness of TRIZ in idea generation and system innovation was demonstrated by exploiting the problem of poor quality arc welding in pipeline maintenance. This is done by combining three tools namely: FA (Function Analysis), CECA (Cause Effect Chains Analysis) are used to analyse the situation and find the key problem, then ARIZ (Algorithm of Inventive Problem Solving) is deployed to solve and search for ideal solutions. Similarly, in [33] the application of TRIZ methods to improve the maintenance of vehicles where special equipment is installed was described. The tools of "Six Sigma", especially statistical process control (SPC) and Pareto analysis, were used to identify the predominant problem. In order to overcome it, the TRIZ method was used and the new solution was analysed by matlab simulation.

Latter, in 2015, in [34] the authors formulated a roadmap to facilitate maintenance problem solving using TRIZ tools. It was proven that TRIZ tools can be used to support

the 37 maintenance guidelines. In 2016 in [35] Contradiction Matrix, is used to determine a remote predictive and preventive maintenance solution. In addition Substance-Field analysis, is used in order to identify problematic situations in the existing maintenance contract and to create specific solutions. In [36] an integrated methodological proposal with a logical step-by-step sequence for solving problems related to the reliability of assets in industrial processes, using high-impact failure mode analysis and a creative proposal for the innovative use of TRIZ in reliability.

More recently, in 2020 a meta-synthesis to identify and extract the factors affecting the choice of maintenance strategy with the TRIZ approach was used [37]. Subsequently 2021, and as an extension of this work the authors identified and compared reactive maintenance strategies with TRIZ principles, developing a TRIZ contradiction matrix by explaining the dimensions and components of each of the reactive maintenance tactics [38].

3.3 Lean and TRIZ: Similarities and Differences

In [39] the author describes an overlap between Lean and TRIZ methodologies. Indeed TRIZ and Lean have many points in common. These are two ways to improve the operation of a system. TRIZ and Lean both look towards the ideal future. They both seek to optimize the use of available resources. However they have some differences. TRIZ focuses on individual elements to be optimized .while Lean considers the entire system to find potential efficiencies. Also in TRIZ, the solution to the problem often uses a resource that was previously considered a nuisance or a waste. While In Lean, the goal is to eliminate waste, because waste means there are inefficiencies and counterproductive actions in the system.

4 Discussion and conclusions

This paper presents work initiated as part of a thesis on the potential contribution of the hybrid Lean-TRIZ approach to maintenance process improvement. The first phase of the project was devoted to researching the topic and reviewing previous research. From the literature review and the research that has been done, we can draw the following conclusions:

From this literature review, it is clear that the application of TRIZ in a maintenance environment has not yet received the necessary attention, and very little work has been done in this area. It is established that TRIZ can be used to build problem solving methods addressing maintenance issues.

Nevertheless, the review of previous studies conducted in this study revealed that the investigation of the applicability of TRIZ tools to maintenance is marginal. Existing research has been largely limited to specific case studies. The integration of TRIZ into maintenance was found in 11 publications, which mainly focused on the use of TRIZ for the development of potential solutions that can be used to solve maintenance problems according to a specific scope which is not surprising. Furthermore, few initiatives have included comprehensive frameworks or models that can integrate TRIZ into the

entire maintenance process outside of specific cases. It can be observed that the vast majority of publications only provide indications of the relevance of the integration of TRIZ in solving maintenance problems. Without having given concrete examples on the sustainability of the proposed solutions. No obvious or simple reason for this limitation was provided in the articles reviewed. Thus the answer to the question of how TRIZ could be useful to improve the maintenance process will remain partial until further explorations are provided.

Lean maintenance, on the other hand, is well known and addressed in various research works as a new approach to apply Lean concepts, tools and techniques to the maintenance function to eliminate time loss and increase efficiency and quality. Many studies have looked at the application of Lean principles and tools in the maintenance environment, analyzing Lean maintenance issues to assess their impact on industrial performance. The results show the effectiveness of achieving predetermined objectives in a maintenance strategy. This is the answer to the question of how Lean has been used to improve the maintenance process.

A number of 31 publications were found. The integration of Lean or TRIZ in the maintenance process is generally beneficial, as proven by several publications. However, none of these publications provided a combination of Lean and TRIZ simultaneously to improve the maintenance process. This indicates that more research on the integration of Lean and TRIZ in maintenance is definitely needed, especially to establish a logical relationship between the two concepts and to see the possibility of their combination as a complete set of tools to improve the maintenance process. Therefore, until further exploration is provided, the answer to the initial question already posed in the introduction on how to use Lean and TRIZ methods to improve the maintenance process will remain partial. The practices resulting from this literature review do not allow any conclusions to be drawn at this stage.

Thus, in-depth work is essential. A complementary approach to the problem posed in this article is to propose a standard "LEAN-TRIZ" improvement model that simultaneously integrates the characteristics of both methods to optimize the maintenance process. Then verify to what extent this new lean-TRIZ approach could be useful. This will be the next step of our research.

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