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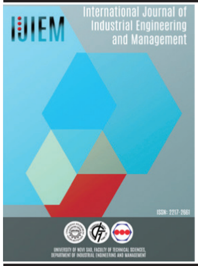

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Original research article

Lean 4.0: An analytical approach for hydraulic system maintenance in a production line of a steel-making plant

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ABSTRACT

The Lean system is widely used in industrial environments, focusing on methods that seek continuous improvement. Industry 4.0 has emerged through intelligent systems aiming to digitalize processes. The interaction of these philosophies establishes significant synergies, which can significantly contribute to the researchers who wish to improve maintenance assets in organizations. This study provides a theoretical approach and empirical support on how Lean 4.0 enables paths to increase the equipment's availability, highlighting TPM 4.0 and Kaizen 4.0 concepts. The achievement results reached a significant reduction in production losses, leading to organizational transformation and a promoting competitive industrial environment with trained employees.

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1. Introduction

Globalization trends are imminent, and companies are increasingly looking to implement proactive strategies. In the steel industry, several devices are subject to random failures, whereby maintenance managers are committed to the production process. The maintenance strategy is one of the ways to reduce costs and unnecessary maintenance [1]. Hydraulic systems are widely used in several organizations, holding multiple advantages where the control and transmission of energy stand out. These systems are prone to breakdowns, where if some failures are not detected and eliminated on time, severe equipment damage and operational safety can occur. Diagnosing malfunctions in hydraulic systems has become a significant challenge in organizations. Nevertheless, by furthering the use of artificial intelligence becomes possible to perform a diagnosis based on field signals such as temperatures, pressures, etc. [2]. A method adopted to increase production efficiency and generate value for customers is the Lean philosophy. In this methodology, value describes any product or service which a customer would be willing to pay. Organizations that implement this system may obtain several advantages, such as increased productivity, increased quality in the production sector, reduced costs, as well as improved technical, functional, constructive, and ecological factors of the finished

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product [3]. Through intelligent industrial systems associated with Industry 4.0, managers can devise strategies based on data collection to overcome existing challenges and take advantage of opportunities arising from new technologies [4]. Thus, autonomous maintenance is directly involved with Industry 4.0 and is represented by self-maintenance as it requires technology use. Companies that deal with activities involving high-risk operations favored this type of strategy. The role of the maintenance operator is changing, consisting of supervising enhanced monitoring systems [5]. According to Nedjwa et al. [6], a growing movement exists to link the Lean management system and Industry 4.0, aiming to eliminate waste from business processes to improve efficiency, reliability, and operational competitiveness. They also mention that a synergy between these two systems exists since they present benefits of interest in a wide range of industries, as well as for the interactive engineering approach to design and simulate industries of the future. To Valamede et al. [7], Lean 4.0 aims to achieve organizational changes by focusing on solutions that seek to meet future market demands, strengthening production competitiveness. The authors identify five attributes associated with the Lean 4.0 system - alignment between processes, devices, and stakeholders; waste minimization and/or elimination; supply chain flexibility; empowerment; and analytical solutions that aim to deliver a continuous production flow. Mattioli et al. [8] mention that maintenance is a vital requirement to increase the service life of operational machinery within organizations. Thus, Total Production Maintenance (T.P.M) is one of the Lean concept tools, which contains a holistic approach to maintenance since it aims to maximize equipment operating time by involving all employees from top management to the shop floor.

Many publications, such as [1], [2], [5], and [8], emphasized the impact of effective maintenance management. Other studies like [4], [5], and [8] relate Industry 4.0 and Lean concepts and their impacts on organizations, or the authors only aborded the connection between Lean and Industry 4.0 in the literature review as [6], and [7]. This present study, in contrast to previous research, provides a theoretical understanding and empirical support on how some concepts of Industry 4.0 and Lean can work together to boost the maintenance of hydraulic systems, especially in steel plants. In this context, this research aims to assist maintenance managers in outlining strategies for reducing the number of corrective maintenance in the hydraulic systems of a production line under the Lean 4.0 perspective to minimize the production losses associated with this equipment. The problem of this research it's framed in data collection over seven years, where the production line under analysis presented high production losses due to corrective maintenance of the hydraulic systems associated with the production processes.

As main objectives, it highlights the problem structuration between the associated tools with Lean and the technologies adopted by Industry 4.0, looking forward to a more competitive industrial environment with trained employees. The research question proposed for this study is expressed: How can Lean 4.0 concepts be applied to promote a cultural change in the maintenance of hydraulic systems of a production line in the steel industry? This study contemplates a theoretical approach and empirical support of how Lean Systems and Industry 4.0 can work together, correlating those items that are most prone to affect the availability of the production line, identifying waste, and optimizing the workforce involved. The sensor's implementation in hydraulic systems will promote better human-machine interaction, promoting considerable progress in maintenance scheduling activities.

2. Literature review

2.1 Industry 4.0

The term Industry 4.0 was first announced in 2011 by the Industry Science Research Alliance working group during the Hannover industrial fair at the request of the German federal government to keep the national industry strong, competitive, and market-leading [9]. Organizations face decisions taken with uncertainty, brought about by growing market competition and increasing customer demands. The fourth industrial revolution, known as Industry 4.0, has developed several technologies to modernize industries like the Internet of Things, Artificial Intelligence, Big Data, and Cloud Computing [10-11]. Tripathi et al. [12] refer that Industry 4.0 is an approach used to control operational performance, just as improvements in the production sector, including a budget, energy consumption, labor, and all production assets. The management from the shop floor becomes a factor of supra importance for Industry 4.0 since it's responsible for controlling all production activities and ensuring operational performance and sustainability, just like removing non-value-adding activities. According to Figure 1, there are the main objectives of Industry 4.0.

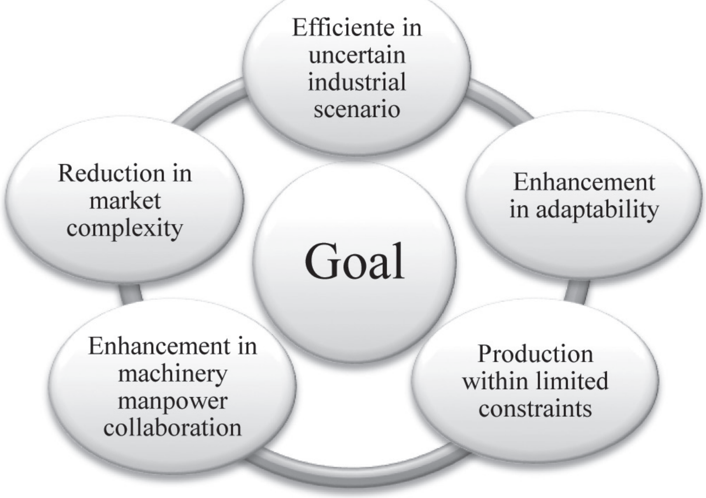

Figure 1. Goals of the shop floor management system in Industry 4.0

Dillinger et al. [13] describe that Industry 4.0 is a methodology oriented to innovative technologies that influence the production environment so that all process assets that generate value become equipped with sensors and actuators, which communicate with a central control station. Some of the technologies associated with the Industry 4.0 support system are depicted in Figure 2.

2.2 Lean

Lean is the concept that gave rise to the Toyota Production System and later became popular in the book The Machine that Changed the World. This concept focuses on eliminating activities that do not add value, known as waste. Three opponent points for the Lean philosophy are waste (Muda), variations (Mura), and overload (Muri) [14]. The Lean philosophy emerges in the context of eliminating waste and with a concept of continuous improvement. This system comprehends a long-term improvement that may take years, aiming to cover all the productive systems of an organization. From the principles of the Lean philosophy with the association of Industry 4.0 technologies, have identified the following concepts: Value, Value Stream, Flow, Pull, Perfection, and People and Teamwork [11-15]. Yahya [16] mentions ten main tools applied to the lean philosophy, such as Total Productive Maintenance (TPM), 5S (Housekeeping), Kaizen (Continuous Improvement), Plan-Do-Check-Act (PDCA), Cellular Manufacturing (CM), Poka-Yoke (Proof Error), Standardized Work (SW), Value Stream Mapping (VSM), Jidoka, and Kanban. Mouzani & Bouami [17] refer that production and maintenance are two distinct processes within organizations, so the concepts applied to Lean Maintenance are not a "mirror" of Lean Manufacturing concepts,

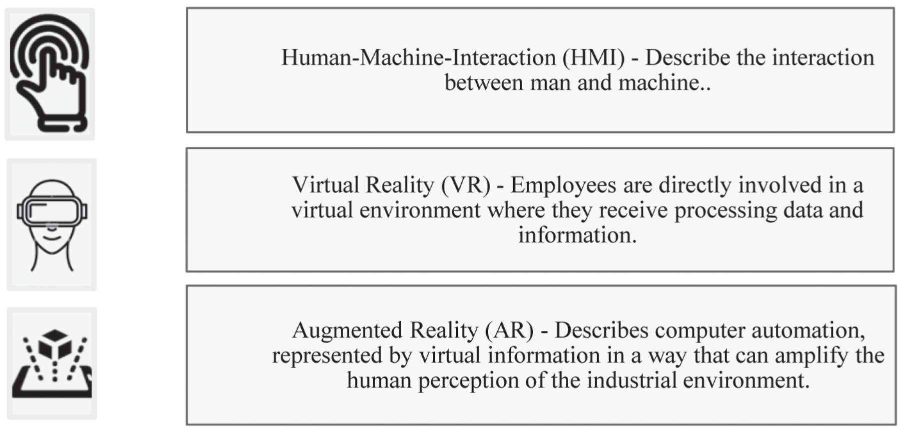

Figure 2. Technologies associated with Industry 4.0

even though had been brought some Lean Manufacturing concepts and tools to Lean Maintenance. Duran et al. [18] explore the differences between waste from Lean Manufacturing and Lean Maintenance philosophies which are connected, as shown in Table 1.

For Antosz & Gola [19], organizations give more and more importance to maintenance, which justifies the implementation of the concepts of the Lean Maintenance philosophy to have "leaner maintenance" in addition to the principles already applied in the Lean Manufacturing philosophy associated with production. The Lean maintenance concept can be defined as a proactive maintenance strategy whose main objective is to provide operational reliability to assets in the most cost-effective way possible. This philosophy is based primarily on the Total Productive Maintenance (TPM) concept, where the principles engage all employees in the organization in maintenance and management activities.

2.3 TPM

TPM is a methodology (see Fig. 3) designed to maximize equipment performance throughout its life cycle, involving all employees, from management to the shop floor. There are eight pillars to TPM: (i) Autonomous maintenance, (ii) Focused improvement, (iii) Planned maintenance, (iv) Quality maintenance, (v) Education and training, (vi) Safety, health, and environment, (vii) Office TPM, and (viii) Development and management. However, 5S plays a vital role in all TPM implementations [20].

Within the 4.0 scenario, preparing a strategy to implement these technologies becomes necessary to avoid high-cost generation in the organizations. As shown in Figure 4, the Cloud, Virtual Simulation, Additive Manufacturing, Augmented Reality, and Big Data Analytics are Industry 4.0 technologies that support TPM. When these technologies

Table 1. Interactions between lean manufacturing and lean maintenance waste

Lean Manufacturing Waste	Lean Maintenance Waste
Material transportation	Spare parts and tools transportation
Manufacture of non-requested goods	Over maintenance
Waiting times between operations	Waiting times between maintenance activities
Overstocked of materials	Overstocked of spare parts
Overprocessing	Excessive or too frequent maintenance activities
Non-conformed products	Rework

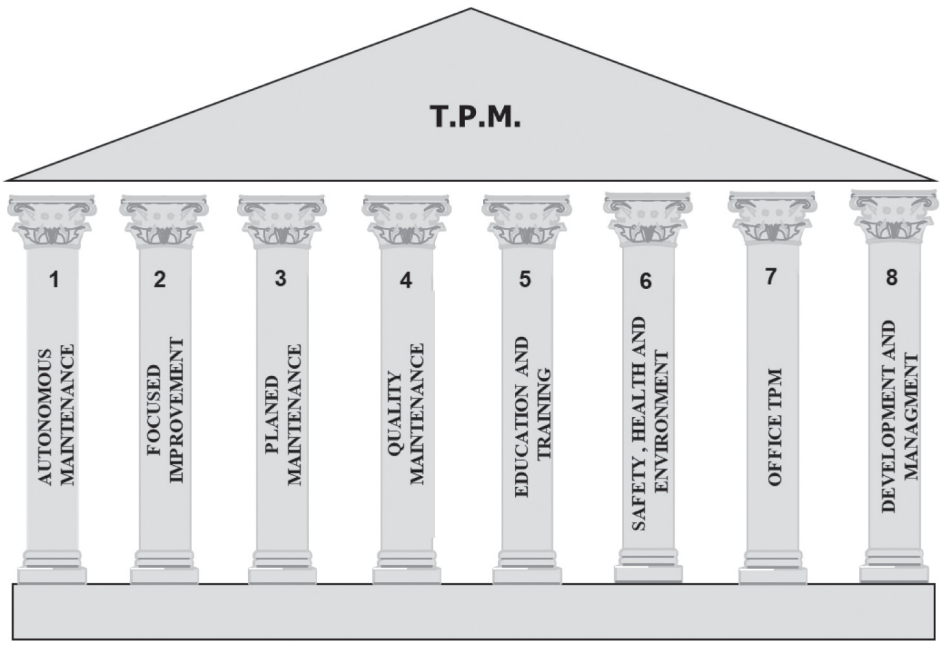

Figure 3. TPM structure

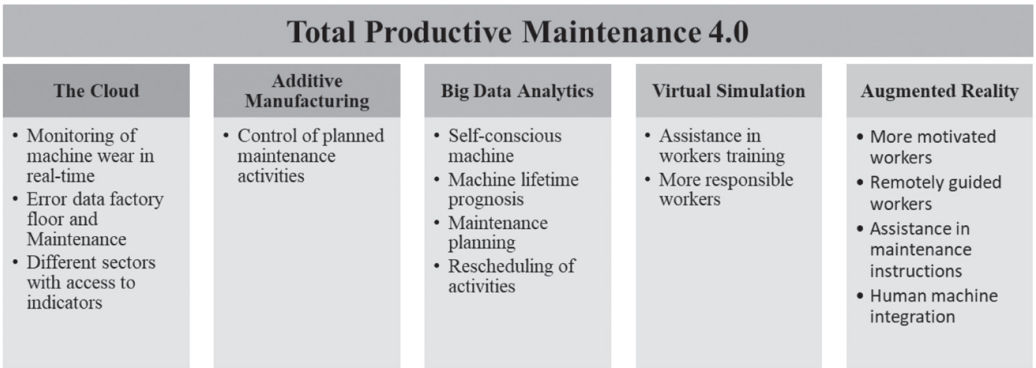

Figure 4. Total Productive Maintenance 4.0

work together, it enables the continuous monitoring of the assets, thus helping to detect errors and send the information to the maintenance teams. Early failure detection results in the prevention of damage and consequentially lower production loss [8].

2.4 Kaizen

Kaizen is divided into two words Kai, and Zen, meaning "to separate" and "to investigate" hence signifying continuous process improvement through the involvement of all employees in an organization, from the top to the shop floor. This methodology has been used extensively through statistical quality control and organizational values that keep employees focused on designing defect-free results, aiming to improve the manufacturing process in the industrial sector. This methodology consists of a strategic management system with performance indicators obtained from metrics, questionnaires, interviews, and direct observation of the assets' and employees' behavior [21]. Figure 5 presents the Industry 4.0 technologies such as the Cloud, Augmented Reality, Virtual Simulation, and Big Data Analytics that support Kaizen methodology. The process data is acquired through intelligent sensors and uploaded to the cloud, where it's analyzed by Big Data Analytics, aiming for results and solutions that provide a continuous flow. Within this conception exists a man-machine relationship since procedural data is available, which makes the employees more critical and able to find possible solutions that give a better performance to the production line [8].

2.5 5S

According to [22-23], 5S is a Japanese business management philosophy that refers to five Japanese words: Seiri, Seiton, Seiso, Seiketsu, and Shisuke, (see Table 2). Each concept associated with each term is related to the other terms and should be jointly implemented in the organizations. This philosophy promotes better cleanliness, use, communication, and assertiveness in the production areas, thus leading to greater satisfaction of all employees in an organization. Therefore, this culture is responsible for quality, productivity, and safety improvement in the industrial sector.

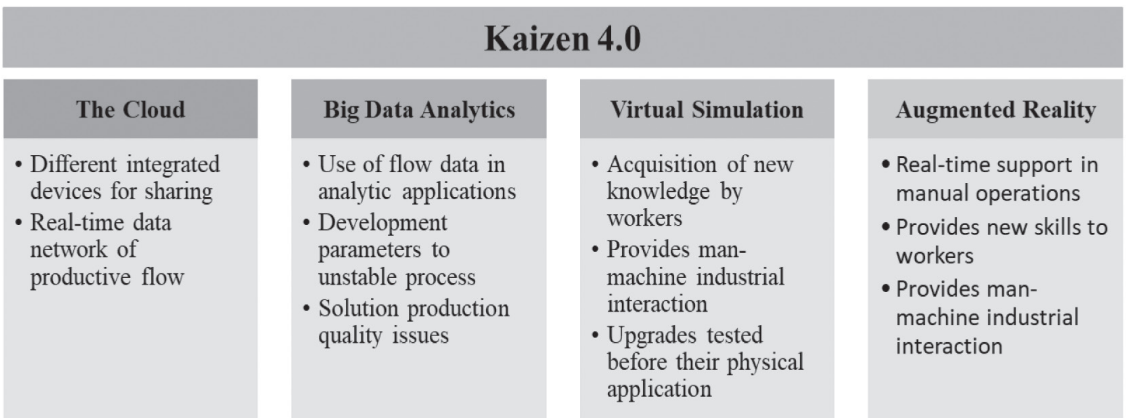

Figure 5. Kaizen 4.0

Table 2. 5S philosophy

Japanese terms	Goal
Seiri	Sort and systematically discard items that are not necessary in the workplace.
Seiton	Arrange necessary items neatly and systematically so that they can be easily retrieved for use and returned after use
Seiso	Clean and inspect the workplace thoroughly so that there is no dirt on the floor, machines, and equipment.
Seiketsu	Maintain a high standard of workplace organization by always keeping everything clean and orderly.
Shisuke	Train people to practice the 5S system continuously so that it becomes habitual and ingrained in the culture of the organization.

2.6 Connections of these concepts according to the aim of this study

According to Lopes et al. [24], maintenance started to perform a fundamental role within organizations as their customers demand higher quality and competitiveness from their products. Many industries operate 24 hours a day, leading their assets to produce at their maximum to handle the production demand. The continuous use of machines leads to increased maintenance activities to ensure equipment performance aiming at a process without failures. As per Lee et al. [25], maintenance strategies over the industrial revolutions have progressively evolved, as shown in Figure 6. For example, corrective maintenance is a strategy type where the actions performed result in equipment repair after a sudden breakdown. This type of maintenance often costs three to four times more than scheduled maintenance. Preventive maintenance performs periodic and scheduled actions according to the kind of equipment.

Crisan et al. [26] cite that all assets of the productive sector involved in maintenance activities must have their priorities related to the strategies to be taken. Therefore, maintenance strategies should diverge according to the level of importance of each piece of equipment, seeking to reach a minimum cost and providing maximum availability and operational reli-

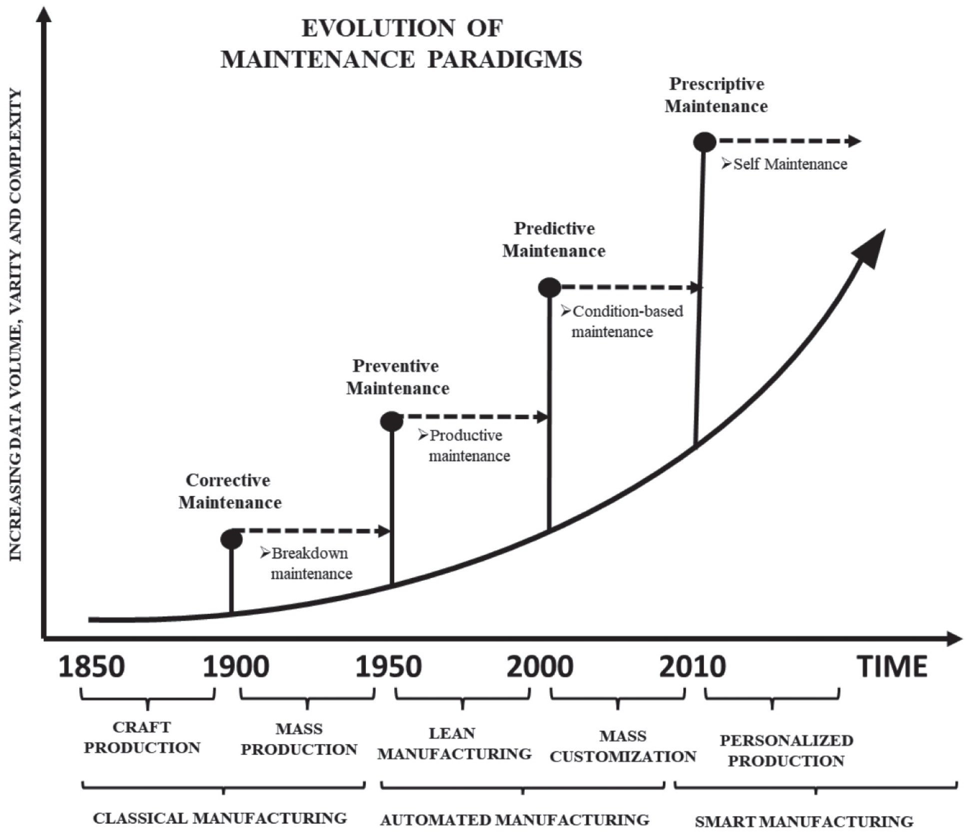

Figure 6. Evolution of maintenance

ability. Figure 7 shows a proposed model for maintenance strategy selection.

With the evolution of technology, maintenance becomes increasingly complex, demanding a careful evaluation of equipment. Toward decreasing the risks of unexpected production downtime, maintenance has evolved into a predictive and prescriptive approach, generally known as the intelligent approach [27]. An improperly selected maintenance strategy can lead to unnecessary production losses, thus compromising the utilization of an organization's assets. For example, predictive maintenance stands as a tool to optimize equipment maintenance in the industrial sector. The pyramid flow for a predictive maintenance application shown in Figure 8 can help to understand how to optimize some types of assets [28].

Hydraulic systems play a crucial role in most industrial plants, where equipment monitoring plays a decisive contribution in aiming to prevent failures at an early stage. Thus, predictive maintenance for these kinds of systems holds paramount importance within organizations [29]. Predictive maintenance is responsible for assets detecting problems in an anticipatory mode and with precise accuracy, thus generating an enormous value for the productive sector. This type of maintenance plays a vital role in organizations and is directly associated with Industry 4.0 since it uses data analytics [30]. Integration between maintenance and Industry 4.0 technologies can provide solutions that simplify the management of maintenance and production systems with a higher production capacity so that organizations can overcome economic, environmental, and social challenges [31]. Korchagin et al. [32] stated that the principles and approaches for Industry 4.0 fit into predictive maintenance processes, which are grounded on continu-

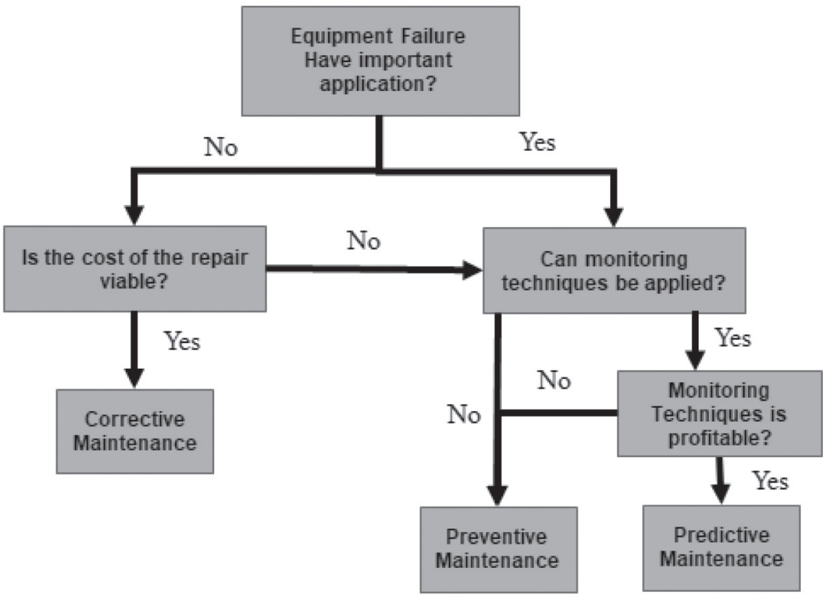

Figure 7. Maintenance strategy selection model

Figure 8. Typical Predictive maintenance and analytic model

ous monitoring through intelligent sensors. By integrating the concepts of Industry 4.0 with predictive maintenance and the Lean philosophy, we get Lean Maintenance 4.0, considering factors like TPM 4.0 and Kaizen 4.0, among others. Through Table 3, the effects of the Lean Maintenance 4.0 philosophy on waste reduction can be observed [16].

The PDCA acronym consists of four steps: P - Plan, D - Do, C - Check, and A - Act. In the P step, problems that need investigation are listed. All the priorities that need to be improved are defined. Usually, the tool used to discover the root causes is the fishbone diagram, commonly known as the Ishikawa. In the D step, plan implementation takes place according to the purpose of the design. In the C step, the process is checked, ensuring that all corrections are deployed effectively. In the last A step, standardization of all activities becomes necessary to avoid repetition of the same problems [33].

3. Research Methodology

This study applies to a production line of a steel industry located in the southeast region of Brazil, with more than 10,000 employees, which operates large equipment such as rolling mills, pickling lines, galvanizing lines, and blast furnaces, among others. Three stages have been performed to demonstrate how Lean 4.0 concepts the maintenance of hydraulic systems in the steel industry. This research is classified according to Table 4.

It is an applied study with a descriptive and exploratory objective once a maintenance data analysis with the association of concepts identified in the literature has been carried out. According to the inquiry mode, this research is quantitative since it uses collected data, and qualitative through bibliographic and documentary survey techniques. It's a case study regarding the method since it explores real situations which lack clearly defined solutions [34].

Table 3. Lean maintenance 4.0 on waste reduction

Type of Waste	Lean Maintenance 4.0
Overproduction	Maintenance 4.0 will help to achieve real-time interconnections with the customer and visibility of the value stream, which will not allow provisioning of nonrequired maintenance tasks
Transportation	All information about the product's performance and its maintenance will be acceptable in digital or VR/AR devices, that's why maintenance team movements will be reduced
Inventory	Maintenance 4.0 enables to have access to the whole information about spare parts warehouses' capacity and provides real-time visibility of the inventory management process
Waiting	Digital technologies in the MRO process reduce waiting on the whole value stream, due to the operative decision-making, simulation of different scenarios, and integrated data management systems
Motions	All unnecessary motions during the maintenance process will be reduced, due to real-time visibility and analysis of the maintenance process, access to actual information about all spare parts, maintenance teams, and processes
Overprocessing	Digital technologies will allow accurate MRO planning and provide all information about the necessary processes and tasks
Defects	The quality of maintenance services will be increased due to the automatic control of human operations and autonomous robots' implementation for simple tasks. In case of defects occurrence, it will be easy to define the process step, which causes this failure, and timely solve this problem.
Insufficient use of human resources	With digital technologies, it becomes easily analyze the staff work and identify non-efficient employees

Table 4. Scientific research classification (Adapted from Kothari & Garg, 2019)

Types of research	
Applications	Applied
Objectives	Exploratory and Descriptive
Inquiry Mode	Quantitative and Qualitative
Methods	Case study and bibliometric analysis

3.1 Bibliometric analysis and literature review

This stage aims to select papers that describe the application of tools associated with the Lean System and Industry 4.0, identifying an interaction between these two methodologies to enable the application of their concepts in steel companies. It took four steps to conduct this proposal.

The first step consisted in selecting the database. Scopus is the chosen database due to the possibility of performing a linked search, for the uniformity of the research characteristics, and for the option of applying the VOSViewer tool. The second step consists in bibliographic research, where the main terms of this research have been selected in the Scopus database from 2018 to 2023. The selection was limited to articles/reviews and open-access papers with publications in English. To summarize the results with the combination of the words: "Lean" and "Maintenance" (356), "Lean" and “Industry 4.0” (187), "Lean" and "Steel Industry" (30), totalizing 573 scientific articles. The third step comprised a search through the VOSViewer software to group the publications and analyze the results obtained in the literature. The fourth step consisted of reading and selecting the documents pertinent to this research, having chosen 50 articles.

3.2 Case study according to the literature review to find the application of Lean 4.0 concepts in manufacturing

The first step consists of identifying the research problem, where it's associated with the production line downtime resulting from corrective maintenance in hydraulic systems. The second step involves data collection for a total period of seven years through the SAP system regarding the maintenance of the hydraulic systems. Identified that all the hydraulic systems have a pre-defined maintenance plan based on the maintenance employees' experience, and predictive and preventive maintenance methodologies are adopted. The third step involves a brainstorming procedure by a committee of experts from engineering and the production line department to identify the possible causes of corrective maintenance of the hydraulic systems. The fourth step has been performed within the Ishikawa diagram, focusing on improving the performance of hydraulic systems through the application of Lean 4.0 concepts. It put forward proposals that recognize the opportunities and challenges of Industry 4.0 associated with Lean Systems. This challenge intends to introduce some Lean 4.0 concepts, aiming to minimize some waste related to the practiced maintenance activities. The fifth step comprised the action plan development, aiming to mitigate the corrective maintenance of the hydraulic systems and implementing the actions associated with Lean 4.0 concerning workforce, method, measure, and machine according to the Ishikawa diagram. The sixth step involves an analysis of the achieved results, consisting of downtime evolution of production losses originated by corrective maintenance.

3.3 Data analysis with experts

This stage includes a data analysis, where are listed the proposals for identifying opportunities and challenges of Industry 4.0 associated with Lean Maintenance. The TPM 4.0 concepts provided automated management through the automation of asset monitoring data that generates graphs, alerts, and warnings, contributing to the support of maintenance management. This data has been provided by sensors that have broadened the overview of the process, making the concepts of Industry 4.0 fundamental to these applications. These measures generated greater autonomy in the operation and maintenance of the equipment, providing significant improvements in man-machine interaction. These actions partly took place since there was not enough money to cover the entire production line. The actions associated with TPM 4.0, and Kaizen 4.0 allowed an instantaneous update of the maintenance indicators, which provided greater assertiveness in decision-making. The implementation of Lean 4.0 generated a culture change, where the training of employees became necessary to achieve solid results.

4. Results

After identifying the research problem in the production line of the Brazilian steel plant, has been carried out a data collection in a total period of seven years through the SAP system regarding the losses of the hydraulic systems. A brainstorming procedure (see Figure 9) has been performed to identify the key factors or variables that can generate corrective maintenance occurrences.

Operational problems and complications are common in an organization, and managers must make the right decision to promote continuous pro-

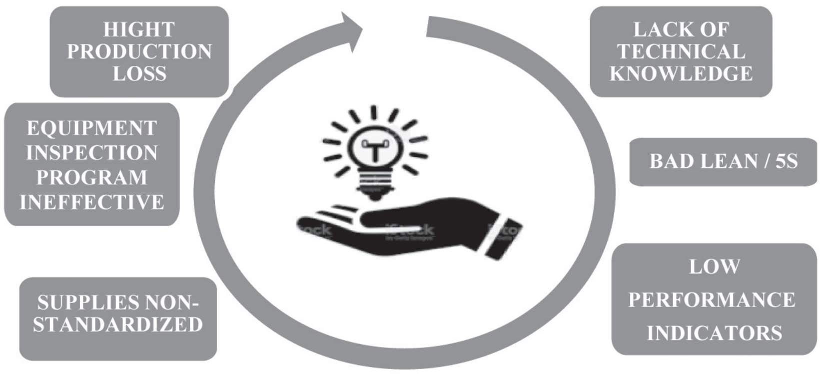

Figure 9. Brainstorming

cess improvement. For this purpose, due to the high number of production losses generated by corrective maintenance in the hydraulic systems, the causes already raised in the brainstorming stage were classified within the *Ishikawa* diagram. This diagram can be described as a graphical tool where it's possible to overview and make decisions to solve the issues that might influence a process under study. The chosen factors by consensus among the experts with the highest impact on corrective maintenance have been red-highlighted in Figure 10.

Seeking an improvement through the Lean 4.0 methodology implementation, the TPM 4.0, *Kaizen* 4.0, and 5S philosophies have been taken into account, correlated with PDCA, aiming to minimize the waste of time associated with corrective maintenance of hydraulic systems. After the Brainstorming overview and the Ishikawa diagram analysis, bibliography research to identify the technologies used by Industry 4.0 associated with the Lean system has been conducted, seeking the application of some concepts of Lean 4.0. A cultural change in the existing maintenance has been proposed to improve the operational performance of hydraulic systems, thus minimizing corrective maintenance. In this context, it has considered the following items related to Industry 4.0 for controlling and ensuring operational performance. Sensors have been installed in some equipment of the hydraulic systems to monitor in real-time the information regarding operating parameters such as pressure, temperature, oil level, dirtiness condition of filtering elements, and the operation performance of hydraulic pumps. This measure has enabled maintenance management indicators to be updated instantly, allowing the maintenance engineer and/or specialist to take appropriate action when parameters are out of range. These actions improved equipment availability and operational reliability, leading to re-

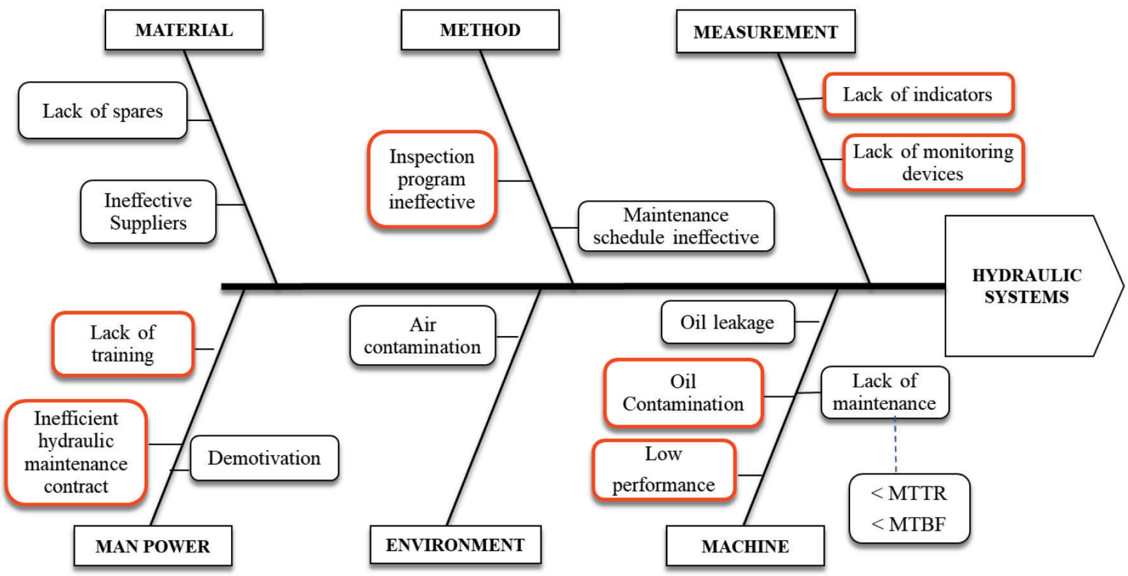

Figure 10. *Ishikawa* diagram

duced corrective maintenance. In this context, productivity has improved, and the scrap rate decreased, leading to an increase in the aggregated value to the end customer once the product can be manufactured with less rework. The need for physical inspections has been reduced since the sensors trigger alerts at the workstation and on the equipment. Now, the inspection time used for the equipment before the sensor's implementation has been shifted to the assets without sensors.

The automated and integrated management of the monitoring data of hydraulic assets that provide graphs, alerts, and warnings to support the decision-making of maintenance managers has been partially implemented since no budget was available for a global implementation on the production line under study analysis. However, technological innovation is not in itself sufficient to ensure operational success. The involvement of all employees, from the management to the shop floor, is necessary to achieve the final goal. In this manner, the TPM pillars implementation showed to be fundamental to maintenance management, where the pillars of Autonomous Maintenance, Focused Improvement, Planned Maintenance, Quality Maintenance, and Employees Training stand out. Thus, the maintenance manager's sponsorship and the worker's commitment were determinants for the TPM pillar deployment. The application of TPM 4.0 became possible through intelligent sensors capable of sending the established parameters of the monitored equipment by cloud computing to software computers, which enable the treatment of data using the concepts of Big Data Analytics. Then, simulated scenarios for the maintenance engineer take an evaluation and subsequent decision-making regarding the moment to perform maintenance on the equipment.

The Industry 4.0 and Lean Maintenance correlations presented significant progress in corrective maintenance reduction, as shown in Figure 12. Industry 4.0 contributes significantly towards the connectivity and overview of the process, yielding improvements in the production sector and increasing the operational reliability of hydraulic systems. Furthermore, Lean Maintenance 4.0 has increased the operational efficiency of the production line. The integration provided the reduction of hydraulic oil contamination, enabling an increment in operational performance, and contributed to leaner maintenance plans with waste reduction. The TPM methodology provided autonomy to the employees who operate the equipment, decreasing response time for troubleshooting, and has provided an upgrade to the workplace by the 5S philosophy of organization and standardization. In this context, the concepts associated with Lean 4.0 provided tools to help maintenance managers in their decision-making, contributing to an improvement in the performance of the hydraulic systems, where there was a reduction in corrective maintenance, as shown in Figure 11.

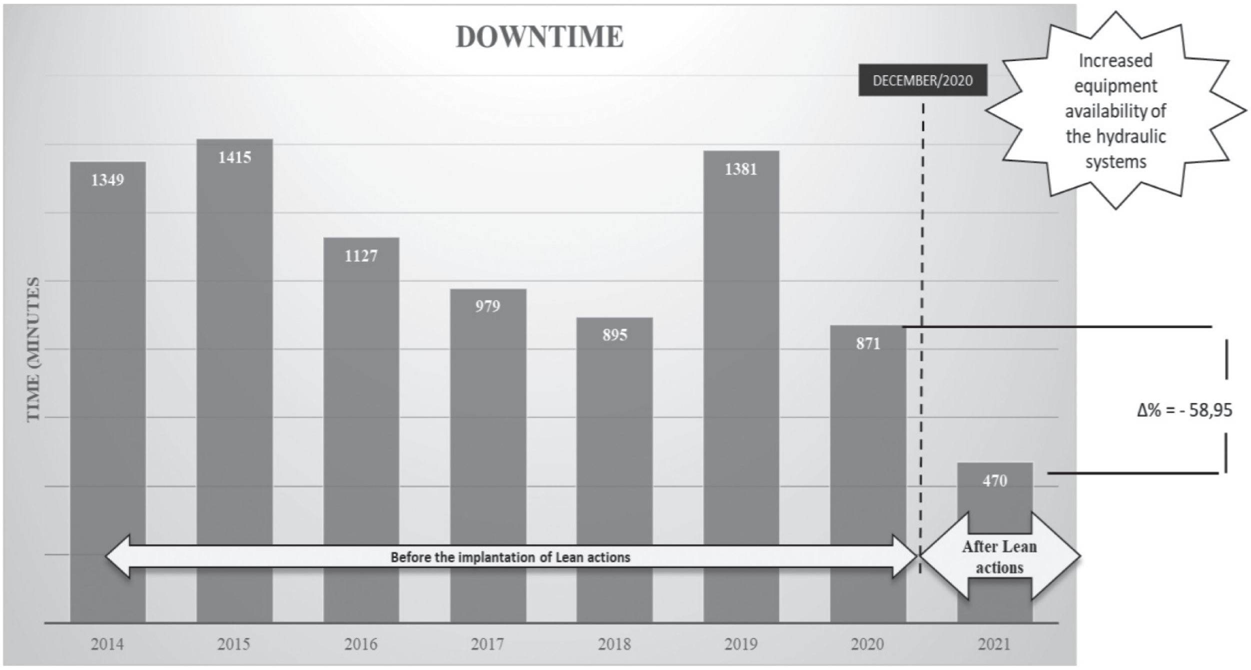

Figure 11. Downtime evolution

As cited by Valamede et al. [7] Lean, and Industry 4.0 concepts involve synergies that support each other, minimizing and/or eliminating waste in organizations. The association of these concepts results in Lean 4.0, focusing on industrial solutions through a change of culture, identifying strategies that allow organizations to keep their businesses competitive in an increasingly globalized market.

5. Discussion

5.1 Theoretical Implications

This research presented results under constant development, which addresses the association of Lean Systems and Industry 4.0 concepts applied in the steel industry. Thus, the results presented in this research are relevant for an investigation under development. The bibliometric analysis conducted via the Scopus database allowed for an understanding of the evolution in this field, where a very significant synergy between these approaches and the steel industry proved to exist.

5.2 Practical Implications

The 4.0 era is becoming a reality nowadays since it promotes relevant industrial and socioeconomic gains and sustainable global development of the steel industry. Through the concepts associated with Lean 4.0, we highlight the implementation of TPM 4.0, which conceived training and autonomy for all employees, thus promoting a better man-machine interaction. This philosophy also originated considerable progress in the planning of maintenance activities.

The concepts associated with Kaizen 4.0 promoted a continuous improvement process through the statistical control indicators management in the maintenance activities, thus contributing to a greater assertiveness in the decision-making process by the managers. The 5 S made available better use and communication in the production areas, promoting greater assertiveness in decision-making, thus contributing to higher employee satisfaction. Industry 4.0 made it possible to monitor the parameters associated with the operational performance of hydraulic systems in real-time, enabling data digitalization. Through this study, it's possible to verify that the integration of these methodologies contributed significantly to a reduction in corrective maintenance, thus allowing an increase in the operational performance of the production line assets.

5.3 Advantages and disadvantages of this study

This research has the advantage of contributing as a theoretical reference for organizations that present problems associated with maintenance management in the industrial sector. This study provides solutions that aim to satisfy future market demands by implementing the concepts of the Lean 4.0 philosophy. As disadvantages, the cost involved in the adequacy of some assets through Industry 4.0 and training associated with this philosophy stands out.

6. Conclusions

The steel industry faces an increasingly competitive and globalized market, where maintenance plays a determining role in quality assurance, operational cost reduction, and asset optimization. The maintenance of hydraulic systems consists of a continuous improvement process aiming to ensure high operational performance, safety, and equipment reliability. Through this research, it is possible to delineate that the principles of Industry 4.0 contribute significantly to the Lean approach since these methodologies enable data digitalization, allowing the monitoring of the parameters associated with the operational performance of hydraulic systems. The lean 4.0 approach significantly contributed to higher asset availability, promoting waste reduction, which is a factor that contributes to a decrease of about 58,5% in production losses and costs associated with corrective maintenance. Through the implementations made, managers now have a holistic view of the hydraulic systems' operation, allowing them to direct support toward the areas where it is most needed once decisions are made based on up-to-date data and in a systematic manner. In addition, monitoring the operational performance of the equipment can become a valuable tool for continuously improving maintenance and production line productivity. Based on these results, maintenance teams can focus on the worst-performing machines. The concepts associated with Lean4.0 contributed to employee training and man-machine interaction, which promotes continuous improvement and considerable progress for maintenance activities planning.

This paper demonstrates the results achieved in the equipment performance, based on the rate of corrective maintenance reduction, promoting the achievement of the steel company's production goals. After conducting this investigation, can be outlined several lessons from discussions with some maintenance managers in the steel industry. These lessons are associated with the main problems identified in managing the maintenance of hydraulic systems to meet future market demands.

The limitations of this research are only related to the maintenance of hydraulic systems, while the concepts discussed above may apply to other types of assets. Philosophies such as Just in Time, *Kanban*, *Poka-Yoke*, or Value Stream Mapping associated with Industry 4.0 can also contribute to increasing the operational performance of asset maintenance, especially *Kata*. This approach provides structured management to develop cyber-physical systems and improve processes through simulations and linked production systems [35], which may also be considered for future studies.

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