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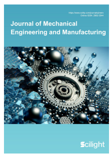

Article

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Lean Approach to Spare Parts Management in a Food Production Company: A Case Study

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Abstract: In a world increasingly driven by competition between companies, where profit constitutes the ultimate determinant of an organisation's survival, it becomes essential to optimise production processes to reduce waste and inefficiencies. Within this context, Lean methodologies emerge as indispensable instruments to enhance the overall productivity of organisations. A critical domain where Lean principles can be effectively applied is equipment maintenance, whose primary objective is to ensure system reliability and prevent production downtime. Within maintenance management, the optimisation of spare parts management plays a fundamental role in sustaining operational continuity and efficiency. This study addresses this specific aspect, focusing on the application of Lean tools to improve spare parts management in an industrial pasta production line. The implemented approach involved the development and integration of a Kanban-based cataloguing system for the existing spare parts inventory. This system facilitated the elimination of obsolete components and significantly improved the speed and accuracy with which workers could identify and retrieve spare parts. Furthermore, the collected data supported a detailed risk analysis of each spare part, enabling the prioritisation of critical components and the optimisation of stock levels. The applied methodology demonstrated tangible results, achieving a total cost saving of €45,445. In subsequent stages of improvement, a software tool was developed to centralise and manage information related to each spare part and its corresponding equipment. This digital integration represented a significant advancement, as it provided warehouse personnel with real-time access to inventory status and allowed maintenance teams to quickly identify and allocate the correct spare parts during equipment failures. Collectively, these developments contributed to enhanced maintenance responsiveness, reduced downtime, and improved overall equipment reliability. Overall, this study contributes to the literature by proposing and validating an integrated Lean-based framework for spare parts management that goes beyond traditional qualitative applications. Unlike existing studies that address isolated Lean tools, the proposed approach combines Kanban-based cataloguing, quantitative risk assessment, Failure Mode and Effects Analysis (FMEA), and digital integration between spare parts and equipment. The proposed methodology is also structured to be replicable and adaptable to other industrial contexts facing high capital immobilization in spare parts.

Keywords: spare part management; lean methodology; risk analysis; maintenance; warehouse management; spare parts obsoletion

1. Introduction

From ancient times to the present day, society is driven by prosperity, triggering the development of products that can fulfil the population's expectations. To create such products, supply chains combining machinery and transportation are established, under the requirement of reliability to ensure the uninterrupted supply of goods to consumers and to enhance the company's capabilities in this sector. Therefore, researchers introduced asset management methodologies capable of preventing failures in the production line, avoiding stops and contributing to the safety of workers [1]. Initially, asset management was focused only on equipment repair and perceived as a less important procedure to be proactively implemented in failure events [2]. However, with the evolution of this field and the need for companies to control production costs and stay ahead of their competitors, the paradigm changed, and asset management became a strategic field in industry. Moreover, the maintenance changed from being strictly applied in the event of a failure to the capability of monitoring components and system deterioration, to predict with relative precision when equipment breakdowns may arise, and thus, mitigating it [3,4]. In this way, further developments in this field are focused on integrating sensors into machines to monitor their conditions, and with the use of mathematical models, understand the relation of data collected with the equipment life cycle [5]. Furthermore, since equipment are integrated into an ecosystem that combines human and financial resources, it has yielded the need of perceiving these assets in a holistic way to understand the link between them and develop an integration management strategy to tie with the policy of efficiency enhancement [6]. Therefore, multiple approaches were created to address these needs, including the Lean methodology, which aims to reduce waste while creating value for the company [7,8]. To pursue this goal, Lean has at its disposal multiple tools that are focused on specific segments of a company's structure, which, when intertwined, impact the company's work culture and catalyse the sense of organisation and efficiency, culminating in the achievement of Lean production. One of the most used tools is the 5S methodology [9,10], which serves as a top-to-bottom tool to improve quality in a company through the implementation of initiatives on physical, intellectual and social perspectives that result in higher productivity [11]. In addition, and more focused on maintenance, TPM surges as an additional tool, with the objective of zero breakdowns, zero defects and zero accidents [12,13], promoting directly the Lean philosophy by guaranteeing a direct flow of the production line with the mitigation of stops due to equipment malfunctions, and therefore, positively impacting the global efficiency [14–16]. Clearly, with the application of Lean tools, the economic benefits are substantial, contributing to the commitment of stakeholders in adopting it [17,18]. Nevertheless, other industrial paradigms like Industry 4.0 (I4.0) also drive the adoption of Lean philosophy because of the support and awareness that the I4.0 technology provides, i.e., I4.0 take for granted the synergistic effect of the autonomous systems implementation with the Internet of Things (IoT) [19], enabling the creation of a framework with inter-asset communication and the production of data that [20], through a process of data analysis, can generate insightful information that allows managers to make better decisions and have a better perspective on how their production systems operate, especially in complex factories like the ones nowadays [17,19,21]. Thus, introducing Lean tools becomes indispensable in this context.

1.1. Lean Overview

The Lean methodology was developed by Toyota to increase the productivity of its factories by eliminating waste and promoting activities that add value to the company. When referring to waste, this includes all types of non-value-added activities such as production delays, over-manufacturing, bottlenecks, poor product quality, and general inefficiencies in the way the various systems within a company interact [22]. In this sense, as the Lean methodology represents a holistic approach, it is not merely perceived as a tool for improving production processes but rather as a philosophy to be adopted by any organisation aiming to maximise its gains and minimise its losses, while simultaneously ensuring the well-being of its employees. This results in the organisation's growth and consolidation within its target market and the strengthening of customer trust. Consequently, the Lean methodology is widely applied across multiple sectors, including banking, healthcare, airports, retail, manufacturing, and government institutions. To ensure its correct implementation, the methodology is based on five fundamental principles (Table 1) [23].

Table 1. Five implementation principles of the Lean methodology.

1. Customer identification and added value specification	This principle aims to conduct a study to identify a company's target customers and to understand the value that these customers place on the company's products [23]. Building on this principle, the entire organisational structure, at both engineering and financial levels, should be oriented so that the customer becomes the core of all production operations [24]. Ultimately, it is the customer who determines whether the developed product provides sufficient added value to justify its purchase.
2. Value stream mapping	This principle seeks to identify all the stages and tasks required for the development of a product according to the specified requirements. Womack and Jones [8] divide this set of tasks into three types: problem-solving tasks, which refer to the evolutionary process of identifying and resolving problems from the embryonic phase of the product to its completion; information management tasks, which address how the chain of command is structured to coordinate all stakeholders involved in the manufacturing process from design to delivery to the customer; and physical transformation tasks, which focus on how raw materials are acquired, transformed into the final product, and subsequently distributed to the customer. By carrying out these tasks, all processes involved in the development of the product are reviewed, and those that truly add value to the product are identified, while those that do not are eliminated.
3. Make the value flow	With the identification of value-adding tasks and the elimination of waste, this third principle focuses on the planning and execution of a strategy that aligns all tasks in synergy, ensuring a continuous and efficient flow. To achieve this purpose, attention is given to reducing production costs while simultaneously increasing the efficiency of workstations to reach higher production rates. Additionally, the waiting time between workstations should be reduced to the optimal point where it is effectively eliminated [23]. By implementing these measures, an ideal state is achieved in which the product progresses and moves between workstations rapidly and consistently, without the need for storage areas in the middle of the process [25].
4. Waste elimination	This principle states that, within the production method, a bottom-up policy should be adopted, that is, as Womack and Jones [8] states, "no one upstream should produce a good or service until the customer downstream asks for it." In this way, every task should follow a pull movement, whereby a product should only be produced or moved to the next stage when it is requested by that stage [26]. By adopting this production policy, overproduction is avoided, workstation stress at specific points in the process is reduced, and consequently, waste generation is minimised. To ensure the successful implementation of this methodology, Cook and Graser [27] highlight that a close relationship with the customer must be maintained to understand their needs and, consequently, synchronise the production chain with the flow of products to the customers.
5. Continuous improvement	The fifth and final principle presupposes the implementation of the previous four principles and calls for their continuous application to achieve the ultimate state in which no waste is generated, and the entire value chain operates with maximum efficiency. In this regard, the Lean culture must be actively promoted in the workplace so that employees become receptive to this philosophy and continuously adopt strategies that align with the objectives of Lean tools.

As a broad philosophy, the Lean methodology must incorporate a range of different tools in its structure to provide a more comprehensive approach to problem detection and resolution (Figure 1). However, these tools must be implemented according to a gradual logic, in which a broad and foundational tool is introduced first, and only once its objectives have been established and consolidated should the subsequent, more specific tools be applied [28]. This process can be understood as an evolutionary learning process, in which fundamental knowledge must first be learned and consolidated before progressing to more advanced areas of expertise. As a fundamental Lean tool to be implemented in the first instance, 5S aims to organise workplaces and promote discipline among workers to improve the efficiency of the production structure. This is achieved through five principles: *Seiri* (sort), *Seiton* (set in order), *Seiso* (shine), *Seiketsu* (standardise), and *Shitsuke* (sustain) [29,30]. Once these principles are implemented and assimilated by workers, the next step involves the improvement of a specific stage within the production process. A sector usually needing Lean improvements is maintenance, a sector usually understood as essential to ensure that all equipment operates under the required conditions and that workers perform their tasks safely. A way to evaluate maintenance performance and enhance system reliability is through the application of

Total Productive Maintenance (TPM), which constitutes a Lean tool that operates proactively by employing more specific Lean techniques such as FMEA [31–34]. This approach allows for the prediction of potential equipment failure modes and based on these predictions, the development of plans to prevent such failures without generating inefficiencies in the production line.

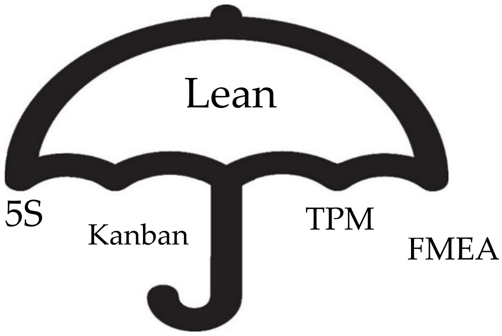

Figure 1. Lean methodology and its tools.

1.2. Maintenance Management

Concerning maintenance techniques, several approaches can be implemented within a system. The type of strategy adopted depends not only on the equipment in question but also on the organisational structure responsible for managing physical assets. More specifically, the technology present in the equipment may determine whether maintenance can be performed remotely through the IoT, whether, as in most cases, a maintenance team must be dispatched to the equipment's location, or whether the equipment itself is equipped with sensors to assist the maintenance team in fault prevention. These premises, combined with the number of employees and their level of training (at the organisational structure level), directly influence the type of maintenance strategy employed. Figure 2 presents the different types of maintenance, followed by a detailed explanation of each approach.

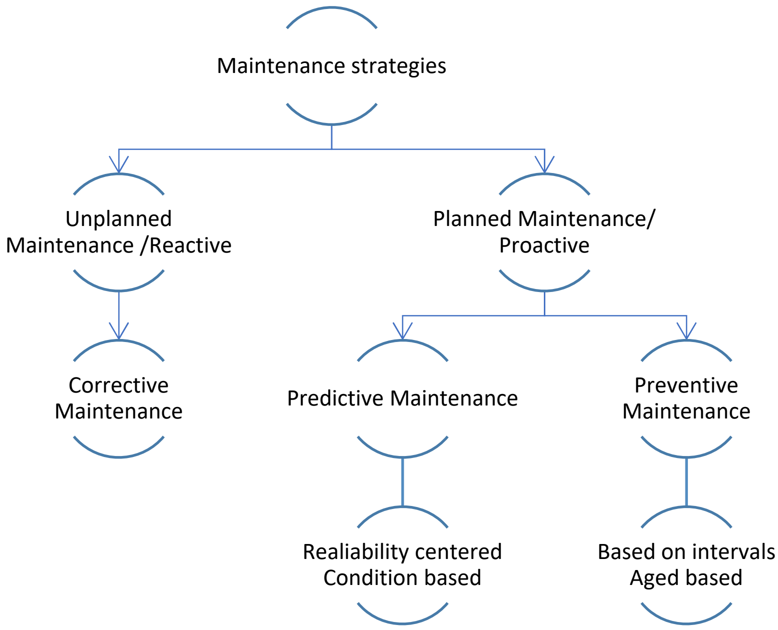

Figure 2. Maintenance strategies.

1.2.1. Corrective Maintenance

This maintenance approach is the most basic maintenance strategy within the hierarchy of physical asset management. It is characterised by being implemented in emergency situations where a failure has already occurred and needs to be resolved so that the equipment can return to normal operating conditions [35]. This type of maintenance does not require prior planning or advanced knowledge regarding asset management, which are precisely the two factors that make it appealing for adoption by some companies. However, in situations where the equipment does not hold significant value and its contribution to the company's operations is limited, corrective maintenance can be considered a viable solution [36]. Nevertheless, in an industrial context increasingly driven by the pursuit of maximum efficiency to achieve higher levels of market competitiveness, and where high-value equipment is used, it becomes essential to adopt maintenance strategies that ensure the equipment operates for the longest possible time while maintaining the required quality standards. In this regard, corrective maintenance does not represent an adequate approach.

1.2.2. Planned Maintenance

Preventive Maintenance adopts a completely different strategy from corrective maintenance, as maintenance actions are not carried out after a failure occurs but instead take place proactively to prevent such failures from happening. This approach aims to avoid unplanned equipment downtime and the consequent impact on product quality. As a preventive measure, this maintenance strategy relies on the early planning of interventions, ensuring that maintenance actions are performed at the optimal time [37,38]. Typically, two main types of systems are used to guide this planning: Time-Based Maintenance (TBM) and Condition-Based Maintenance (CBM) [39]. In the case of TBM, as the name suggests, all maintenance planning is based on the expected operational lifespan of a component before failure. Accordingly, several maintenance actions with different levels of intervention are scheduled throughout the machine's life cycle to replace components before they fail [36]. CBM, on the other hand, does not rely on estimations but on the actual condition of the equipment. This allows for more accurate decision-making regarding the timing of maintenance interventions, thereby preventing unexpected failures. Moreover, CBM contributes to greater efficiency in spare part management, since knowing the real-time condition of components allows maintenance tasks to be scheduled closer to the end of a component's useful life, thus maximising its potential utilisation, something that TBM does not usually achieve. Another significant advantage of CBM is the ability to detect emerging failures that may not have been initially considered in the maintenance strategy.

Despite the clear advantages of both TBM and CBM over corrective maintenance, their implementation requires a larger and more technically skilled workforce, particularly in the case of CBM. However, the benefits that these strategies bring to an organisation are substantial [40,41]. Therefore, when evolving towards more advanced maintenance strategies, the transition should be carried out gradually, with by training and development of human capital.

1.3. Lean Tools in Maintenance

The Lean philosophy, being a holistic approach, also incorporates physical asset management within its methodology as a means of ensuring increased productivity and added value for an organisation. More specifically, maintenance serves as a fundamental asset for achieving the objectives of the Lean philosophy, since maintaining a reliable production line inherently reduces downtime caused by equipment failures, thereby contributing positively to the overall efficiency of the company. In this sense, maintenance should evolve towards a Reliability-Centred Maintenance (RCM) approach through the application of Lean tools, to minimise maintenance-related waste, reducing spare part consumption, and improving the efficiency of maintenance activities [42]. When applying the Lean philosophy to maintenance, it should follow the five fundamental principles of the Lean methodology. Initially, to identify value-adding activities, the 5S tool can be implemented [43]. In this first stage, employees are encouraged to adopt a work culture of excellence, leading to an initial reorganisation of workplaces that allows workers to locate and use tools more efficiently [36]. This process also helps identify, for later stages of the Lean methodology, the equipment that represents the greatest value to the organisation. Still within this initial stage, but following the workplace reorganisation, and considering both the type of equipment and the available human capital, the most suitable maintenance strategy should be selected, whether TBM or CBM. Subsequently, in the second stage of the Lean methodology, once the maintenance strategy has been selected, the FMEA tool should be used to assess the failure risks associated with a given piece of equipment and the actions required to mitigate those potential failures [44,45]. By evaluating the possible failure modes of a machine and their consequences, it is possible to draft a maintenance plan that efficiently allocates resources to prevent equipment failure. In this regard, human resources are deployed so that expertise and labour are concentrated where the impact is greatest, while material resources benefit from improved spare parts management because FMEA makes it possible to identify the components most likely to fail [46]. The combination of these measures thus contributes to increased productivity, cost reduction and the elimination of interruptions in the production chain [47]. With the maintenance strategy defined according to the FMEA, still within the second stage of the Lean methodology a more in-depth analysis should be carried out to identify and eliminate waste occurring in maintenance activities. This includes Lean tools such as the Fishbone diagram to identify root causes of waste, and visual tools such as Kanban, which, through the implementation of visual boards, enables better organisation by workers and thereby prevents the generation of waste [44,48]. Moreover, within visual tools, mapping all maintenance and related activities clarifies existing inefficiencies, bottlenecks and delay times [49]. In addition, other usual inefficiencies found are [50]:

- Rework, in some cases due to lack of experience of workers the maintenance work needs to be redone;
- Centralised maintenance, which forces workers to waste time in dislocations for collecting spare parts or tools;
- Excess of transportation of materials;
- Inefficient collection and storage of data, in which high amounts of data are collected from the machines but are not analysed to draw conclusions from it, or not crossed with other indicators;
- High lead times of material as a result of bad planning regarding stocked parts;
- Unproductive maintenance from the point of view of conducting predictive and preventive analysis in short periods of time, when the timing between this type of maintenances must be with the biggest gap as possible.

According to Dragone, Biotto and Serra [50], the third and fourth principles of the Lean methodology, in relation to maintenance, are interconnected within a single stage. At this stage, the processes and Lean tools implemented in the first two stages are now applied and assessed in terms of their effectiveness. With the maintenance strategy in place, data from the machines is collected and stored in a centralised information system to which all workers involved in the process have access, enabling them to consult the operations status. With this information gathered and consolidated, it also becomes possible to better planning organisational strategies for future actions [51]. Furthermore, this type of platform serves as an interface for information exchange between supervisors and operators, supporting work organisation and the assignment of work orders. Thus, with all tools implemented, including information collection, the performance of the maintenance strategy must be evaluated [52]. For this purpose, different types of standardised indicators are used to assess various parameters, allowing conclusions to be drawn regarding the efficiency of the maintenance strategy defined, and, most importantly, to identify discrepancies between actual and expected performance. One of the indicators used is the Mean Time Between Failures (MTBF), which, as the name suggests, calculates the average time between component failures. This metric helps determine whether the new maintenance strategy performs better than the previous one, or whether adjustments are required to increase the time between maintenance interventions, thereby improving equipment management efficiency [53]. Another indicator employed is the Mean Time To Repair (MTTR), which measures the time elapsed from the start of the maintenance team's intervention until the equipment is fully repaired [54]. This provides insight into the maintenance team's performance, particularly regarding diagnostic and repair times. Concerning the overall evaluation of an asset, the Overall Equipment Effectiveness (OEE) is one of the most widely used performance indicators, as it reflects the equipment's availability, performance, and product quality [55,56]. Therefore, it is used to assess the impact of upgrades and strategic changes implemented on the equipment.

In the final stage of implementing Lean tools within maintenance, the focus is on the application of continuous improvement. This stage involves re-evaluating the results obtained from the performance indicators and, based on these outcomes, making the necessary adjustments to the implemented measures. In a subsequent phase, a new strategy may then be adopted to further eliminate waste and inefficiencies that remain within the process. This stage should once again serve as a means of transferring knowledge, while also promoting a culture of excellence and organisational awareness among workers, so that each individual, within their own workplace, can contribute to increasing productivity by embracing the Lean methodology.

1.4. Spare Parts Management

Following the principles of continuous improvement established within the Lean methodology, the optimisation of spare parts management emerges as a crucial dimension in sustaining efficient maintenance practices. Spare parts management represents a fundamental pillar in supporting maintenance activities and, consequently, in determining the overall efficiency of production systems.

The primary objective of spare parts management is to ensure the organised storage and availability of components, allowing maintenance interventions to be carried out in the shortest possible time. Failure to achieve this goal directly impacts the MTTR and compromises the operational efficiency of the production line. In this regard, Lean tools play an active role in improving spare parts management, particularly through the implementation of a pull-based system within stock warehouses [57]. This approach ensures that spare parts are supplied to maintenance operations only when required, reducing unnecessary capital investment in inventory and freeing up valuable storage space. Determining the correct quantity and type of parts to keep in stock must be guided by the FMEA for each piece of equipment. Through this analysis, it becomes possible to identify components with a higher probability of failure and to estimate their expected lifespan. This information supports data-driven decisions regarding which spare parts should be stocked and in what quantity, balancing reliability with cost-efficiency. Beyond stock quantity, the overall cost of spare parts management can be influenced by two major factors. The first concerns ordering costs, which include expenses related to transportation, processing, and inventory handling. From an economic perspective, these costs can be reduced by grouping orders from the same supplier, thereby distributing logistical and administrative expenses across a larger number of parts. The second factor relates to storage costs, as it is necessary to monitor the condition of parts in stock and, when required, adopt appropriate recovery measures to preserve their functionality [58]. By integrating Lean principles into spare parts management, organisations can significantly improve their maintenance efficiency, reduce waste, and ensure that operational reliability aligns with the broader objectives of Lean production, namely, the pursuit of value creation through continuous improvement and waste elimination [59].

2. Problem Characterisation

The case study presented in this article focuses on a company operating in the food sector which, as such, is equipped with machinery to produce cereal-based products. To ensure the proper functioning of this equipment and to prevent downtime due to breakdowns, maintenance activities are carried out internally, which has led to the creation of a dedicated maintenance department. Within the maintenance framework, it is necessary to maintain a stock of spare parts. However, in the case study presented in this article, the organisation and planning of this stock are carried out without following a recognised good practice management methodology, resulting in a significant amount of capital (€790,000) being immobilised in spare parts inventory and contributing to the company's financial inefficiency. In addition, due to a lack of planning in acquiring spare parts to meet equipment maintenance needs, some parts become unfit for use because their lifespan expires when they are stored for extended periods, or because equipment manufacturers release upgrades that render them obsolete. Therefore, in this study, following a Lean methodology, a framework will be developed that aims for the spare part stock efficiency enhancement, saving physical and economic assets to the company, more specifically, expecting to obtain the following measures:

- Procedure for admitting and releasing parts from the inventory;
- List of critical spare parts;
- Plan to describe the spare parts needed in stock based on the existing equipment's;
- A procedure to improve the inefficiency in maintenance planning.

Although spare parts management is widely addressed in the literature through inventory control models and isolated Lean tools, many industrial implementations remain fragmented, relying on partial solutions that do not integrate risk, criticality, equipment dependency, and information flow. In the analyzed case, the absence of a structured methodology linking spare parts to equipment criticality, maintenance planning, and real-time information resulted in excessive capital immobilization, obsolete inventory, and increased maintenance response time. This scenario shows a gap between Lean principles and their operationalization in spare parts management, which this study explicitly aims to address through an integrated framework that can be replicated to other organizations.

3. Methodology

This study follows a case study research strategy, aiming at analytical over statistical generalization. The selected company was chosen due to its high spare parts inventory value, heterogeneous equipment base, and absence of a structured spare parts management methodology, conditions that are representative of many medium-to-large manufacturing organizations. While the empirical validation is conducted in a single company, the proposed framework can be applied in other production environments with similar maintenance and inventory challenges.

Given the significant issue regarding spare parts management, the approach to solve it must be deep and involve multiple structural changes. Therefore, it was decided, in cooperation with the company's administration and in line with good management practices, that general improvements should first be implemented. Subsequently, from the Lean philosophy perspective of continuous improvement, more effective and in-depth management changes can be introduced in the future. Accordingly, this study was divided into three main areas (Figure 3): Spare Part Evaluation, Link Between Spare Parts and Equipment, and Equipment Improvements.

- Regarding the spare part evaluation, a new parts identification system will be implemented, allowing for the proper cataloguing of all existing components following the Kanban principles. In this study, the implementation example focuses on parts belonging to production line equipment. With this information, a risk analysis will then be presented for each piece of equipment on the production line;
- The link between spare parts and equipment represents another area of improvement to be addressed in this study, and it arises as a consequence of the maintenance management assessment. This section describes the creation of a system that establishes a direct link between spare parts and the corresponding equipment based on their maintenance plans, and the availability and location of the respective spare parts within the warehouse;

- Finally, in the third area, equipment improvements, an analysis will be conducted to lead to an upgrade of a specific piece of equipment to increase its reliability. Consequently, this will reduce the number of spare parts required in stock, saving the company tied-up capital in spare parts.

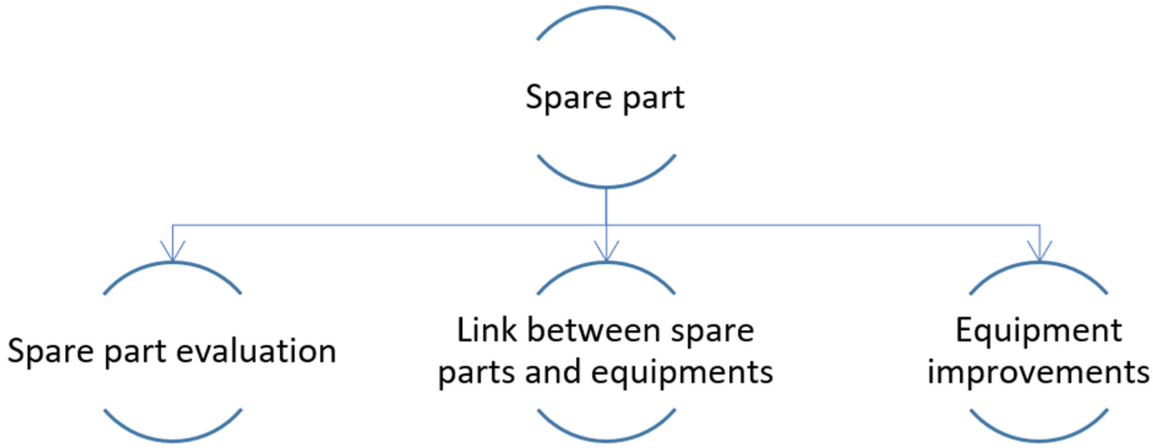

Figure 3. Studies field of improvement.

In applying management improvements to the three different sectors highlighted in Figure 3, Lean tools will be utilised to enhance overall effectiveness. Thus, in Figure 4, a diagram is represented showing which type of Lean tools are used and in which stage of the process.

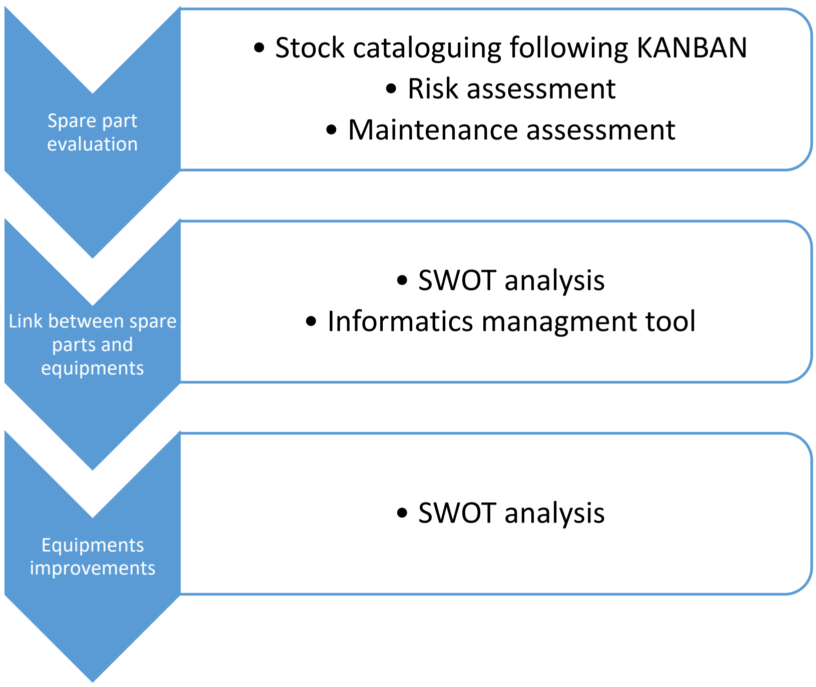

Figure 4. Lean tools implemented in their corresponding study field.

4. Results

4.1. Spare Parts Evaluation

4.1.1. Spare Parts Evaluation Procedure Overview

Firstly, contributing to the development of improved spare parts planning, an assessment was carried out of the components currently in stock. This assessment will also serve as the basis for the creation of an individual card for each part, following the Kanban principles, to enable the cataloguing of the entire existing inventory and the establishment of an internal database for real-time consultation of the available spare parts and their condition. Accordingly, for each type of spare part, the information presented in Table 2 was collected.

To calculate the risk stated in Table 2 the following equation is used:

$$Risk = Cost \times Criticality \times Lead\ time \quad (1)$$

The values of cost criticality and lead time used in Equation (1) are the values determined in Table 3 based on the spare part characterization done with the parameters of Table 2.

Table 2. Parameters for stock cataloguing.

Parameter	Description
Name	
Internal code	
Location	This code is constituted by two letters, to organise the storage area like a matrix, i.e., the first letter corresponds to the storage region and the second letter to the shelf where the part is stored.
Part condition	
Associated equipment	
Criticality	Based on the supplier manual for each machine, each part was classified into three levels regarding the impact that presents on the equipment operation: A (non-critical), B (critical) and C (vital).
Lead time	
Annual demand	Based on the number of parts bought each year
Cost	
Number of parts stored	
Value in the warehouse	Based on the number of parts stored and the cost of each one
Risk assessment	Classifies if the part needs to be stocked, according to the following level: ≥75: Needs stock. 25 ≤ value < 70: Needs a deeper evaluation to choose if stock is required. Value < 25: Unnecessary to stock.

Table 3. Values for risk calculus.

Part Criticality	Cost	Lead Time
1-Level C	1-Above 5000 €	1-Below 7 days
3-Level B	3-Between 500 € and 5000 €	3-Between 7 and 15 days
5-Level A	5-Below 500 €	5-Above 15 days

For each type of equipment, and for different brands within the same type of equipment, the defined cataloguing model was applied. In this way, a higher level of organisation of the spare parts in the warehouse was efficiently achieved. The most frequently used parts, based on maintenance history and annual demand, were placed near the entrance to the storage area, so that during maintenance operations the time spent by maintenance technicians travelling to and from the stock area could be optimised. Furthermore, through the identification and removal of obsolete parts, additional space was made available in the storage area for other company needs, thus preventing unnecessary expenditure on the creation of extra storage capacity. The remaining information collected was imported into the company's software management system, representing an improvement over the previous procedure, since the limited information available before the implementation of this method was kept in paper format and only by a few employees, making it difficult to share information and promote collaboration among staff in promoting good stock management practices. To ensure that any employee could operate and access the digital system, a one-point lesson was developed and added to the existing ones.

To conduct a more in-depth analysis, the next step was a general assessment of the impact of each piece of equipment on the capital invested in stock, based on the information collected.

4.1.2. Dough-Making Ricciarelli Machines

Regarding the Ricciarelli producing machine, this piece of equipment is used for products with low production series, namely to produce small-calibre pasta, which is packaged by the machine itself through a vertical gravity-filling process.

By analysing the data in the Table 4, it is possible to conclude that the impact of this equipment on the total value invested in stock is approximately 4.4% (a share of 34,600.07 € out of 790,000 €), and that the spare parts for the Ricciarelli packaging machine represent only 1.7% of the total parts stored in the warehouse. This leads to the conclusion that this equipment has a low impact on the company's investment in stock. However, some obsolete spare parts were identified, amounting to 5616.43 €, representing waste that will be eliminated through the implementation of the new spare parts management methodology. The new step performed was a risk assessment to select the parts that need to be stocked, based on Equation (1), so that spare parts that are currently stocked but no longer needed can be discarded. Thus, improving the free space for other needs that the company might require in the future, diminishing the invested capital in parts, and reducing waste by having fewer degraded parts as a result of storing them for extended periods.

Table 4. Ricciarelli machine spare parts analysis.

Total Value of Spare Parts in Stock	**346,00.07 €**
Number of parts in stock analysed	91
Number of obsolete parts found	28
Obsolete parts total value	5616.42 €
Number of FMEA parts	43
Total value of FMEA parts	16,660.29 €
Average Lead Time	17.4 days
Average part cost	282 €

From the analysis of a total of 91 spare parts in Table 5, it was identified that only 86 require stock. However, after deducting the 27 obsolete parts, this number decreased to 59. Moreover, it was possible to verify that there were four parts requiring a more detailed analysis to determine whether their storage was viable. After meeting with the maintenance department managers, it was concluded that it was not necessary to keep these four parts in stock, as they could be standardised into a single component. These parts corresponded to support plates only different in colour, but exactly equal; by standardising them to a single colour, only the aesthetic aspect was affected and not the functional one, thereby ensuring a reduction in the capital tied up in stock.

Table 5. Ricciarelli machine spare parts risk analysis.

	#		#	**Fraction of Risk**	**Value €**
Stock	86		59	68%	19,566 €
Evaluate	5	−27 obsolete parts	4	32%	9418 €
Unnecessary to stock	0		0	0%	0 €
Total	91		63	100%	28,984 €

Regarding the parts identified through the FMEA method (Table 6), it was concluded that, out of a total of 43 parts, 38 necessarily require stock, two do not, and three require a more detailed evaluation. For these three parts, in agreement with the maintenance technical team, it was decided that two of them did not need to be kept in stock, as they are standard rubber components and have a short lead time.

Table 6. Ricciareli identified FMEA parts risk analysis.

	#	**Fraction of Risk**	**Value €**
Stock	38	85%	14,237 €
Evaluate	3	5%	823 €
Unnecessary to stock	2	10%	1600 €
Total	43	100%	16,600 €

In summary, from the two criticality assessments carried out, it was possible to achieve a reduction in stock expenditure of 11,318 €.

4.1.3. Dough-Making Rovena Machine

This type of equipment is designed to produce long-cut pasta and can operate at high throughput rates, making it suitable for large-scale production runs. As with the equipment described in the previous section, the pasta is packaged vertically by gravity. However, the Rovena machine also allows the application of a label on each package to facilitate quick opening.

In the case of the Rovena equipment (Table 7), its monetary impact on the capital invested in stock is approximately 8.7%, with a total of 100 spare parts, of which six are obsolete, representing a cost of 70 €. Although the cost of the obsolete parts is relatively low, it nonetheless represents waste that should be eliminated. In this case, the parts did not become obsolete due to degradation caused by prolonged storage, but rather because they were components used in a retrofit performed for a specific and one-off situation and are no longer applicable. Accordingly, a standard work was established stating that retrofits should only be carried out in cases where they prevent equipment downtime. This approach helps save human resources otherwise used for retrofit work, ensures the use of certified manufacturer components (providing greater reliability), and prevents unnecessary storage of spare parts. Regarding the average lead time, it is approximately 21 days, as the parts are providing from foreign countries.

Table 7. Rovena machine spare parts analysis.

Total Value of Spare Parts in Stock	69,291 €
Number of parts in stock analysed	100
Number of obsolete parts found	6
Obsolete parts total value	70 €
Number of FMEA parts	41
Total value of FMEA parts	5488 €
Average Lead Time	21 days
Average part cost	382 €

With information collected regarding each spare part, their risk management was assessed next in Table 8.

Table 8. Rovena machine spare parts risk analysis.

	#		#	Fraction of Risk	Value €
Stock	93		87	92.7%	54,417 €
Evaluate	7	−3 obsolete parts	7	7.3%	14,803 €
Unnecessary to stock	0		0	0%	0 €
Total	100		94	100%	69,221 €

Of the parts evaluated in Table 8, none were classified as storage was not required, and seven were identified as needing further assessment. Following this additional evaluation, it was decided that these parts should be kept in stock, as their average lead time is relatively high (21 days).

Following the risk analysis of the parts selected through the FMEA assessment in Table 9, it was observed that 39 parts require stock in the warehouse, while two do not. In total, across both risk analyses, it was possible to reduce by eight the number of part types to be stored. Of these, as previously mentioned, six were obsolete and two did not require stock, resulting in a cost reduction of 1670 €. This represents a relatively small saving (2.3%) when compared with the 69,291 € invested in stock before the implementation of the risk analyses. Higher savings (14,803 €) could have been achieved if the parts listed in Table 8, which were evaluated, had been classified as unnecessary to store. However, a more conservative decision was made to prevent potential shortages caused by their relatively long lead time.

Table 9. Rovena identified FMEA parts risk analysis.

	#	Fraction of Risk	Value €
Stock	39	85%	3888 €
Evaluate	0	5%	0 €
Unnecessary to stock	2	10%	1600 €
Total	41	100%	5488 €

4.1.4. Dough-Making Teepack Machine

The Teepack machine is designed to fill small-sized packages with low-calibre pasta. In addition, it is characterised by its high production rates, which make it ideal for large-scale production runs. It is also capable of applying a label to the package, allowing for quick and easy opening.

Considering the results obtained from the cataloguing of the parts related to the Teepack equipment in Table 10, it can be concluded that this machine accounts for 10% of the total value invested in stock. Among the equipment analysed in the previous and subsequent sections, it represents the highest stock investment. It was also verified that no obsolete parts exist, as the equipment is new to the factory and there are no records of a similar machine previously installed on the production line. Furthermore, it was determined that each part costs, on average, 370 € and has an average lead time of 28 days, due to the parts supplier being based in a foreign country. Next, a risk analysis of the parts was carried out.

Based on the risk analysis of the items corresponding to the Teepack equipment (Table 11), 128 were found to require stock, while four required further evaluation. Following consultation with the maintenance department, it was decided that these four items did not need to be stocked. This decision was influenced by the fact that the equipment is relatively new, meaning there is a certain guarantee of reliability provided by the supplier during the first years of operation. Additionally, the components in question are heating resistors, for which preventive maintenance procedures include measuring electrical consumption and resistivity to identify whether they are likely to fail in the near future. This enables their purchase in advance and replacement before failure occurs. To ensure that this operational logic is consistently followed, the described resistor control procedure was added to the preventive maintenance manual.

Table 10. Teepack machine spare part analysis.

Total Value of Spare Parts in Stock	**77,403 €**
Number of parts in stock analysed	132
Number of obsolete parts found	0
Obsolete parts total value	0 €
Number of FMEA parts	32
Total value of FMEA parts	12,966 €
Average Lead Time	28 days
Average part cost	370 €

Table 11. Teepack machine spare part risk analysis.

	#	**Fraction of Risk**	**Value €**
Stock	128	97%	62,387 €
Evaluate	4	3%	15.016 €
Unnecessary to stock	0	0%	0 €
Total	132	100%	77.403 €

The criticality analysis of the parts selected through the FMEA assessment in Table 12 revealed that 26 needed to be stored and six required further evaluation. After assessing these six parts, it was decided that they did not need to be stocked, as they presented an average lead time of 15 days and, more importantly, a high cost (4218 €), which would contribute to unnecessary capital immobilisation. From the two criticality analyses carried out, although no parts were initially classified as not requiring stock and the parts requiring further evaluation were also ultimately deemed unnecessary to store, a total cost saving of 19,234 € was achieved.

Table 12. Teepack identified FMEA parts analysis.

	#	**Fraction of Risk**	**Value €**
Stock	26	90%	8748 €
Evaluate	6	10%	4.218 €
Unnecessary to stock	0	0%	0 €
Total	32	100%	12.966 €

4.1.5. Ishida Scale Equipment

The function of the Ishida weighing machine is to weigh the pasta and divide it into portions of the correct quantity, after which the dough-making equipment carries out the filling of the packages. For the weighing machine to achieve a high throughput rate and match the filling pace of the dough-making machines, it is equipped with multiple scoops fitted with load cells, allowing several weighings to be performed simultaneously.

Based on the data presented in Table 13, it can be concluded that the impact of the stored parts belonging to this equipment represents a very small fraction (0.3%) of the total stock value. This is mainly due to the low complexity of this type of equipment, which, in addition to having few moving parts, operates with relatively simple mechanisms, as its primary functions are to weigh and divide specific portions of pasta. As with some of the previously analysed machines, the average lead time is relatively high, since the components must be imported, with the lead time stabilising at around 20 days. However, in this case, although the FMEA analysis identified two parts as critical, they were not ultimately considered as such. The parts in question are a scoop and its corresponding load cell. On a first approach, this decision might appear questionable, however, because the equipment is fitted with multiple scoops, if one scoop and its load cell fail, the operator can deactivate these components, and the machine will continue operating at the required pace to supply the dough-making machines.

This allows sufficient time for new parts to be ordered and later replaced. Regarding obsolete parts, ten were identified, resulting from the decommissioning of another machine of the same brand but from a discontinued series.

Through the risk analysis of the spare parts (Table 14), it was verified that all components require stock. Therefore, the analysis of this equipment did not result in any financial savings for the company, with actions limited to the removal of spare parts that were already discontinued. However, although no reduction in invested capital was achieved, the amount of capital tied up in stock for this equipment is also low, representing less than 0.3% of the total stock investment.

Table 13. Ishida scale equipment spare part analysis.

Total Value of Spare Parts in Stock	**2453.75 €**
Number of parts in stock analysed	32
Number of obsolete parts found	9
Obsolete parts total value	1055.14 €
Number of FMEA parts	2
Total value of FMEA parts	0 €
Average Lead Time	20 days
Average part cost	32.62 €

Table 14. Ishida scale spare parts risk analysis.

	#		#	**Fraction of Risk**	**Value €**
Stock	32		22	100%	1398.61 €
Evaluate	0	−10 obsolete parts	0	0%	0 €
Unnecessary to stock	0		0	0%	0 €
Total	32		22	100%	1398.61 €

4.1.6. Ricciarelli Scale Equipment

Similar to the Ishida weighing machines, the Ricciarelli scales perform the weighing and dosing of pasta through multiple scoops equipped with load cells, ensuring that the dough-making machines receive the correct quantities for filling the packages.

Through the identification and cataloguing of spare parts, following the parameters defined in Table 2, it was verified that only eight items correspond to the Ricciarelli machines (Table 15), representing a financial impact of just 0.3% relative to the total number of items stored in the warehouse. Furthermore, no obsolete parts were identified. Similar to the Ishida weighing machines, the components classified as high-risk in the FMEA analysis are the scoop and its corresponding load cell. However, since the equipment is fitted with multiple scoops, and even if one becomes damaged the machine can still maintain the required production rate, these seven FMEA-classified critical components do not require stock. For this equipment, the average lead time is lower, at approximately 13.9 days.

Table 15. Ricciarelli scale spare parts analysis.

Total Value of Spare Parts in Stock	**2325.51 €**
Number of parts in stock analysed	8
Number of obsolete parts found	0
Obsolete parts total value	0 €
Number of FMEA parts	7
Total value of FMEA parts	0 €
Average Lead Time	13.9 days
Average part cost	537.54 €

Following the risk analysis in Table 16, it was confirmed that there are no components that do not require stock or that need further evaluation to determine whether they should be stocked. Therefore, it can be concluded that the stock management for this equipment was correctly planned. Furthermore, contributing to this outcome is the fact that the equipment is of low complexity and operates under nominal conditions, which prevent failures. As a result, the maintenance department does not stock a wide range of parts, as failures in this equipment are not frequent.

Table 16. Ricciarelli scale spare part risk analysis.

	#	Fraction of Risk	Value €
Stock	8	100%	2325.51 €
Evaluate	0	0%	0 €
Unnecessary to stock	0	0%	0 €
Total	8	100%	2325.51 €

4.1.7. Yamato Scale Equipment

This equipment, similar to the two previously described weighing machines, is equipped with a system comprising multiple scoops and their respective load cells, which are responsible for weighing and dosing a predefined quantity of pasta to supply the dough-making machines for package filling.

The values presented in Table 17 indicate that the components in stock belonging to the Yamato weighing machines represent approximately 0.4% of the total capital invested in stock, which constitutes an insignificant proportion. In the case of this equipment, unlike the other weighing machines presented in previous sections, obsolete parts corresponding to it were found. However, these were classified as obsolete not due to degradation, but because they were discontinued following an equipment upgrade. Of the three parts selected through the FMEA analysis, the criticality assessment revealed that they did not require stock for the same reasons identified in the cases of the Ishida and Ricciarelli weighing machines. The observed lead time was approximately 20 days, as the parts must be imported, a relatively high value, and the average cost per part was 1107.41 €.

Table 17. Yamato scale spare part analysis.

Total Value of Spare Parts in Stock	3522.04 €
Number of parts in stock analysed	27
Number of obsolete parts found	8
Obsolete parts total value	1204.23 €
Number of FMEA parts	3
Total value of FMEA parts	0 €
Average Lead Time	20 days
Average part cost	1107.41 €

Based on the risk analysis of the items associated with the Yamato weighing machine in Table 18, all of them were classified as requiring stock, representing a total value of 2317 €. From this amount, the cost of the obsolete components (1204.23 €) was deducted, as these had already been discontinued.

Table 18. Yamato scale spare part risk analysis.

	#		#	Fraction of Risk	Value €
Stock	27		19	100%	2317.81 €
Evaluate	0	−8 obsolete parts	0	0%	0 €
Unnecessary to stock	0		0	0%	0 €
Total	27		19	100%	2317.81 €

4.2. Link between Spare Parts and Equipment

Another approach outlined for warehouse optimisation was the development of a software tool in the form of an equipment tree, which consolidates the relationship between existing parts, the corresponding equipment, and their availability and location within the warehouse. This tool works as an computer app that workers and technical staff can handle, and by uploading the technical information of each part and its location on the warehouse and associating it with the relevant equipment, as result, this software tool assists the maintenance team in performing maintenance tasks by identifying which parts may be close to failure and indicating the location of that category of parts in the stock warehouse, as well as the specific part to be used. This not only prevents equipment downtime due to failures but also optimises the work of the maintenance team by reducing time wasted on diagnostics and searching for spare parts in the warehouse. Furthermore, as the system is also designed to allow production teams to report equipment failures, it automatically generates a work order for the maintenance department specifying the fault and the required maintenance action. This streamlines the interaction between departments and reduces the maintenance response time to incidents. In addition, since all work orders and parts used are recorded in the system, it enables greater control over the number of components consumed, thus allowing the monitoring of component usage to prevent waste or discrepancies.

By implementing this software tool in accordance with the proposed guidelines, it is expected that both the efficiency of maintenance operations and the management of stock movements, namely the input and output of parts, will be significantly improved. However, the development and deployment of this software tool require the allocation of resources and may entail potential issues during its implementation. Therefore, a SWOT analysis was conducted to provide a more holistic understanding of the potential strengths and weaknesses associated with the software.

By evaluating the conducted SWOT analysis (Figure 5), it becomes possible to gain a clearer understanding of what to expect from the implementation of the software. From the perspective of the Strengths, as indicated, clear efficiency improvements are anticipated both in spare parts management and in maintenance operations, by identifying which components belong to each piece of equipment and their corresponding location within the warehouse. Moreover, by developing this tool, in which all information is consolidated, and work order records are stored, it was identified that new Opportunities may arise from the implementation of the software. These include the potential to adopt new TPM methodologies and to detect inefficiencies within the system that would otherwise be difficult to identify with the currently available information. Therefore, these two factors, Strengths and Opportunities, surpass the identified Threats and Weaknesses, which are primarily related to the interaction between operators and the software, as staff training will be required and data import errors may occur. Nevertheless, the time invested in training is in the company's best interest, as it will enable the realisation of the benefits associated with the implementation of the software. Furthermore, the occurrence of data import errors can be easily mitigated through the adoption of a work methodology that promotes double-checking of all import operations.

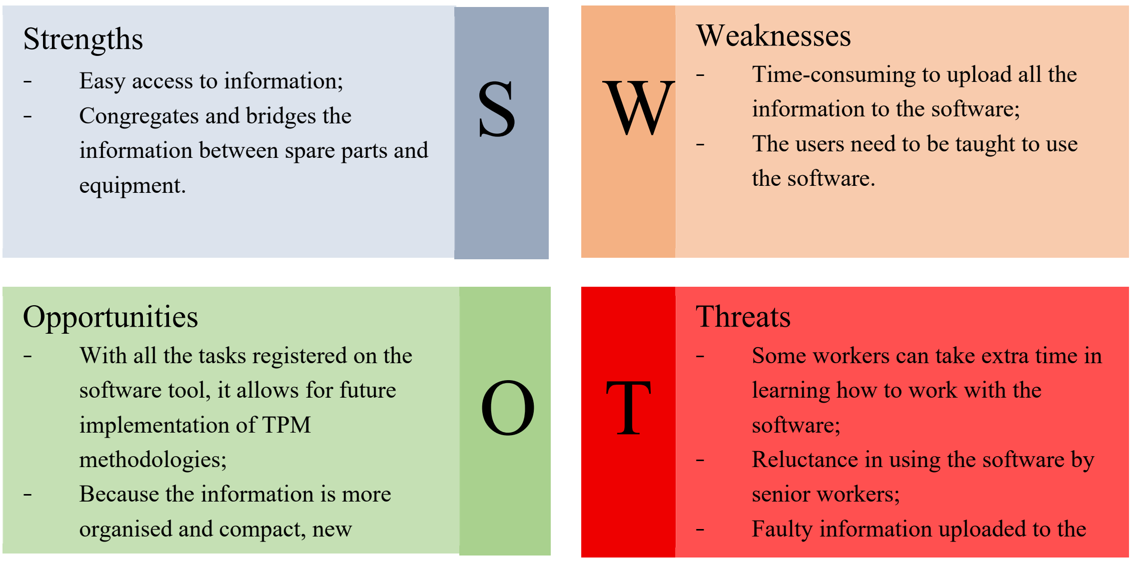

Figure 5. Link between spare parts and equipment SWOT analysis.

To implement the software, the procedure followed was based on the information collected in Section 4, in which all data relating to the spare parts, including their characteristics, serial numbers, and warehouse locations, were imported into the system. To establish the connection between the spare parts and the equipment installed on the factory floor, and in addition to using the reference information already gathered in Section 4, several meetings were held with both warehouse and maintenance personnel. During these sessions, the spare parts associated with each piece of equipment were identified based on maintenance records and the respective equipment manuals. Within the software itself, a database was created to prevent information loss in the event of a system failure, with automatic backup copies scheduled to ensure data security. Simultaneously with the software development, employees received training on how to operate the system, and an operational rule was established requiring all imported data to be verified three times during the import process, to minimise the risk of errors.

4.3. Machine Improvements

To reduce the number of spare parts held in stock, it was considered to carry out equipment upgrades to increase their reliability and, consequently, reduce the number of spare parts required. In addition to upgrades, another strategy could involve ensuring compatibility of components across equipment from different manufacturers, that is, implementing adaptations in machines with the same function but from different brands, so that they can all use the same spare parts. This approach would enable the standardisation of the spare parts inventory, thereby significantly decreasing the quantity of parts that need to be stored.

To understand whether implementing such equipment improvements represents a reasonable strategy, a SWOT analysis was conducted.

From the SWOT analysis in Figure 6, it can be observed that, although equipment upgrades may offer significant advantages, there are potential Weaknesses and Threats, such as the possible non-compliance with established standards and the high costs associated with the upgrades, which may outweigh the financial benefits resulting from the reduction of capital invested in spare parts. Therefore, before any modification is implemented, an economic feasibility study should be conducted to determine whether the proposed change is viable. When analysing the existing equipment, it was identified that the mechanism responsible for applying the film to the pasta packages could be standardised across all dough-making machines, regardless of brand. To assess whether this modification would generate economic savings, the maintenance records were examined to determine how many of these mechanisms had already been replaced and the associated costs. The analysis revealed that, after the first three years of operation, failures in the film application mechanism began to occur more frequently, primarily in the machines of the Teepack brand, while the Ricciarelli machines experienced only two failures. Upon requesting a quotation for the components required to standardise the mechanism across all machines, a total cost of 333.20 € was provided. This led to the conclusion that implementing the standardised system would not be economically justifiable, as failures predominantly occurred in only one brand of machine, and the cost of storing one spare mechanism per brand (105 €) is lower than the cost of the modification itself.

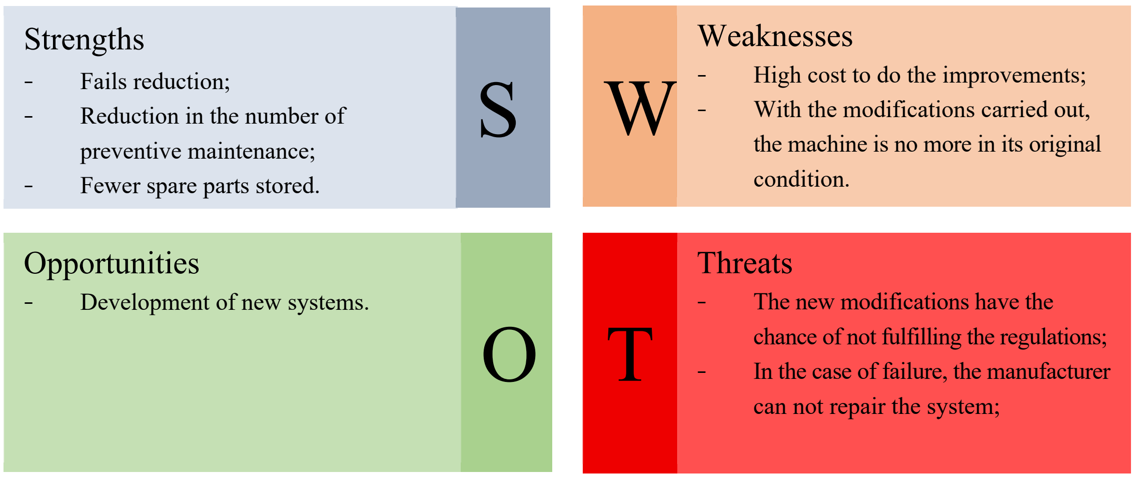

Figure 6. Machine improvements SWOT analysis.

5. Discussion

With the application of Lean tools throughout the study, it was possible to improve the overall efficiency of the case study. The initial cataloguing of the existing spare parts in the warehouse not only allowed the collection of information regarding each spare part, but also enabled their classification according to the information presented in Table 2, so that a Kanban-style card could be created and associated with each spare part. Through this initial data collection, it was possible to organise the spare parts in the warehouse and, consequently, reduce the time required by maintenance teams to identify a specific component.

In addition, by assessing critical components using an FMEA analysis, identifying obsolete parts, and calculating the risk associated with each component for each piece of equipment, it was possible to understand both their impact on the warehouse in terms of required spare parts stock and the associated cost to the company. This assessment showed that the impact of production machines on the total investment required for spare parts is relatively low (71,507.66 EUR). However, the savings achieved through the adoption of Lean tools amounted to 45,445 EUR, representing 63.55% of the required investment and approximately 5% of the total value invested in spare parts across the factory. In view of these results, and considering the relatively low impact of production machines on spare parts investment, an initial analysis should have been carried out to identify which sector of the industrial unit represented the highest share of spare parts investment, so that Lean tools could have been applied to that sector in order to achieve greater savings in a more efficient manner.

The development of a software tool that integrates the technical information of each component, its criticality based on an FMEA analysis, and its physical location in the warehouse enabled a reduction in MTTR by improving the agility of maintenance technicians in locating spare parts. Furthermore, it also contributed to a reduction in

MTTF through the implementation of new maintenance plans aligned with the criticality of each component as defined by the FMEA analysis.

6. Conclusions

Considering the initial problem described, the application of Lean tools made it possible to significantly improve the efficiency of the spare parts management process. The implementation of a parts cataloguing system, associated with a technical datasheet in the format of a Kanban card, not only enabled the immediate identification of each spare part's characteristics and its location in the warehouse, but also allowed the assessment of its conservation status and technical specifications. With this approach, it was possible to remove obsolete components from stock, resulting in a direct reduction of the capital tied up in storage. In parallel, the systematic collection of technical information for each part made it possible to carry out a criticality analysis, aimed at determining which components needed to be stored, thereby eliminating unnecessary parts and reducing costs associated with idle capital. The results of this analysis revealed total savings of 45,445 € in a global investment of 790,000 € in spare parts. Although this reduction represents approximately 5% of the total investment, it constitutes a considerable amount in absolute financial terms. Additionally, a spare parts management software was developed to integrate and centralise information regarding each spare part and the corresponding equipment. This digital solution brought significant operational benefits, namely greater agility for workers in accessing real-time stock conditions and a faster response during maintenance interventions, as the required spare parts could be located more efficiently. Therefore, a reduction in the MTTR indicator of the equipment was achieved. Finally, the possibility of improving equipment reliability through technical upgrades was assessed to reduce the number of spare parts required. However, the economic analysis showed that the investment needed for these upgrades would not be compensated by the savings resulting from the reduced stock. Therefore, it can be concluded that a more viable alternative would be the adoption of a predictive maintenance strategy, as this would enable real-time monitoring of equipment condition, allow more accurate prediction of component failures, and consequently optimise the number of spare parts held in stock.

Although the proposed framework was validated through a single industrial case study, the methodology relies on widely adopted Lean principles, risk-based decision criteria, and standard maintenance practices, which supports its applicability to other manufacturing contexts. Nevertheless, the quantitative results obtained (e.g., cost reduction) are naturally influenced by the initial maturity level of spare parts management and the characteristics of the production system. Future research should apply the proposed framework in different industrial sectors and production configurations to further assess its viability.

Author Contributions

R.D.S.G.C.: conceptualization; R.D.S.G.C., A.J.V. and I.M.P.: methodology; A.J.V., A.G., I.F., M.B. and I.M.P.: data curation, visualization; D.A.: writing-original draft preparation, investigation; R.D.S.G.C., M.B., A.J.V., A.G. and I.F.: supervision; R.D.S.G.C., M.B., I.F., A.G. and I.M.P.: validation; R.D.S.G.C., A.J.V., M.B., I.F., A.G. and I.M.P.: writing-reviewing and editing. All authors have read and agreed to the published version of the manuscript.

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Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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