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Adaptation of the Lean 6S Methodology in an Industrial Environment under Sustainability and Industry 4.0 Criteria

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Abstract: Industry 4.0 paradigms have a positive influence on standard operating procedures, methodologies used in Lean Manufacturing techniques and management models with sustainability criteria. Interdependencies and correlations have been found between Lean systems and Industry 4.0. The Lean principles of avoiding waste and zero defects are related to the cloud and big data paradigms. In a current workplace, there has been an exponential increase in digital information and the need to generate direct commitments to environmental management. This situation forces us to innovate and improve the management methodologies and models used in the industrial environment. The Lean 6S methodology must adapt and respond to new demands. In this work, an update of the Lean 6S methodology is carried out to guarantee increased productivity in the workplace through the organization of industrial resources, both physical and digital. A revision of the implementation procedure is proposed, which includes activities that generate a direct commitment to sustainability and the organization of digital information, through a proposal for an organizational architecture of Industry 4.0 technologies.

Keywords: ODS; Industry 4.0; sustainability; lean 6S; PLM; ISO 14001

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1. Introduction

The current productive paradigm is not sustainable because environmental alteration, mostly through global warming and environmental pollution, is closely related to industrial production [1]. In addition, large numbers of non-renewable resources (oil, coal) continue to be consumed, and the aging of the population is leading to a shrinking workforce [2], so there is no doubt that there is a need for innovative initiatives to achieve a commitment to a sustainable and connected environment.

The international standard ISO 14001-2015 [3] establishes on its environmental management objectives how to contribute to sustainable development: "the control or influence on the way in which the organization designs, manufactures, distributes, consumes and carries out the final disposal of products or services, using a life cycle perspective that can prevent environmental impacts from being involuntarily transferred to another point in the life cycle".

In addition, it must be noted that on 25 September 2015, world leaders adopted a set of global goals to eradicate poverty, protect the planet and ensure prosperity for everyone as a part of a new sustainable development agenda. Each goal has specific targets that should be achieved in the next 15 years. To achieve these targets, everyone has to contribute: governments, the private sector and civil society [4].

On the other hand, the current literature shows that there are direct effects of Industry 4.0 technologies (I4T) on lean manufacturing practices (LMP) and sustainable organizational performance (SOP) [5–9]. So, taking this research into account, a need to improve the impact of I4T is observed on those Lean methodologies related to reducing waste, people and teamwork, especially on those I4Ts more commonly used, such as the Internet of Things (IoT) and simulation [10]. Therefore, it is important to review and update the scope of I4T in terms of optimizing the implementation process of Lean methodologies and, in the end, increasing the level of productivity of organizations.

The objective of the Lean 6S methodology is to improve process quality and increase plant productivity, eliminating all types of waste and with an extra focus on safety in the workplace [10–13].

On the other hand, to organize companies' information, there are tools such as CRM (Customer Relationship Management), ERP (Enterprise Resource Planning), PLM (Product Lifecycle Management) and SCM (Supply Chain Management), as well as cloud work through virtual servers (CLOUD) and information processing through big data tools [14]. Nowadays, the industry is also immersed in the search for and implementation of solutions that could facilitate the implementation of digital production models, where the integration of different cyber-physical systems in correlation with new socioeconomic factors requires a review of the leadership, organization and business model. In this review, you must put the change epicenter in people and their talent at one end and people and their experience at the other.

The Lean 6S methodology could be a solution to drive sustainable and innovative committed leadership established on Industry 4.0's strategy paradigms. This leadership should lead to a digital model implementation for services and capital goods production and consumption, with high flexibility and real time interactions during production between machines, people and products [15,16]. The following statements can be highlighted regarding the application of Lean 6S and Industry 4.0 in a sustainable environment [17]:

- The environmental effect of Lean 6S is mainly related to waste reduction.
- Lean 6S is mainly used for reducing variations in products and processes.
- Only a few studies have introduced Lean 6S in combined Industry 4.0 and LCA approaches.
- The actual research work is mainly focused on the product rather than the system life cycle.
- The introduction of Industry 4.0 allows more insight into the manufacturing processes' data, thus producing a greater opportunity and expected outcomes of Six Sigma application.

2. Material and Methods

Considering the scope of the Lean 6S methodology, this research aims to adapt the methodology of efficient and safe organization of physical spaces to the correct use of the necessary materials and the management of high volumes of digital information. It is essential to standardize a commitment that allows achieving optimal results in environmental management and digital organization in the workplace.

Based on the procedure defined for the implementation of Lean 6S [12], in this research it is proposed an adaptation of the methodology, using a revised flow diagram and an iterative process based on the PDCA cycle, to achieve continuous improvement. This adaptation ensures that, during the implementation of the 6S, the application of criteria based on sustainability commitments and the adaptation to a digital transformation environment are taken into consideration. It should not be forgotten that the application of this procedure continues to require discipline and teamwork.

Lean methodology has become a widely spread approach to increase the efficiency in enterprises' processes. Nowadays, Industry 4.0 is one of the most promising approaches to cope with future challenges in the production environment. It is shown that a process-orientated organization, and thus, Lean Production Systems, might be an enabler towards a successful and sustainable implementation of Industry 4.0 in the production environment [18].

Quality improvement techniques highly rely upon the collection and analysis of data for the purpose of solving quality-related issues. Synergy of Lean Manufacturing and six sigma aim to reach the quality levels of 3.4 parts per million defects by reducing the variations in processes. Industry 4.0 is tending toward the digitalization of manufacturing activities with powerful data analysis methods that can drive meaningful results out of the big data available [19].

It is evident that the leap towards a digital methodology must be due to one of the following reasons [20]:

- An industrial company "pressured" by a client in coherence with ISO27001 on information security;
- A strategy that was created from the physical (the workshop and then the office) and went to digital information;
- A process that needs better management and includes the ICT provider;
- Manage the treatment and resolution of ICT service requests by email and manage internal communication;
- Organize a common folder with resources shared by a large group;
- Organize the work of an ICT department and the service that it provides to the organization;
- Organize collaborative environment together with the classic file management system in the traditional operating system;
- Organize systems where different devices are used and ensure access to information on the move;
- Regulate a work system with internal messaging tools;
- Organize the work with a document manager (Alfresco, Moodle, Intranet . . .).

Continuous improvement (CI) is a key component of lean manufacturing (LM), which is fundamental for organizations to remain competitive in an ever more challenging market. At present, the new industrial revolution, Industry 4.0 (I4.0), is taking place in the manufacturing and service markets, allowing more intelligent and automated processes to become a reality through innovative technologies [21]. Industry development technologies have been established to allow for the widespread use of IoT in industrial processes, the integration of cyber-physical systems (CPS), the construction of cyber-physical production systems (CPPS) and the start-up of smart factories [22]. The integration of cyber-physical systems must be carried out horizontally (in the value chain), as well as vertical (from sensing the process parameters to real-time decision making) [23].

What is the basis of digital transformation that can allow companies to lay the foundation for their strategy? Although there are different approaches [5,19,24,25], one of the most complete is the Smart Industry 4.0 Study [26], which proposes a set of 12 paradigms that generate both quantitative and qualitative benefits. The references to consider are the following: autonomous robots, mobility, RPA, simulation, additive manufacturing, new human interfaces, Internet of Things (IoT), blockchain, horizontal and vertical integration, cybersecurity, big data, artificial intelligence and cloud computing.

These paradigms or references of technological scope can be grouped into six areas:

1. Flexible robotics. Collaborative robotics to unite and share machine capabilities with people's skills;
2. Advanced mechatronics. Advanced mechanical technologies to make processes more flexible and automated;
3. Big data and cloud computing. Taking advantage of their potential by streamlining their management and analysis processes;
4. Internet of Things. Sensorization of the systems to monitor their use;
5. Advanced materials. The demand for new products for which new materials and consequently new processes adapted to these new realities are necessary;
6. Additive manufacturing. Ability to produce 3D parts or components from the addition of different layers in 2D.

In this sense, the Lean 6S methodology must evolve and adapt to flexible and efficient implementation criteria. This adaptation must be achieved through the integration of information technologies that allow the use IoT, big data, cloud computing and other services, and with the corporate commitment to permanent innovation [7,19].

Due to the unstoppable increase in digital information and the new informational culture, the risk of information overflow (emails, Internet, mobile, tablet, etc.) must be avoided, because it causes a disorder due to the continuous appearance of unnecessary digital resources that could ultimately cause a loss of commitment to order and discipline in culture.

This is the reason why the obligation to develop the competencies that allow personnel to acquire a commitment to environmental management of the resources of his job and to perform a correct management of information should not be forgotten. As indicated in the ISO 14001 standard, the worker has to technically navigate through contents and organize, focus and transform that information into concrete and useful knowledge for their work. The review of workflows under a common approach and a risk-based thinking must ensure that the committed decisions are made in the workplace with different management systems and especially with environmental management systems and the development of the digital management model.

Companies that consider the integration of Industry 4.0 paradigms use three types of integration [23]: horizontal integration through value networks to facilitate collaboration between companies, vertical integration of hierarchical subsystems within a factory to create a flexible and reconfigurable manufacturing system, and end-to-end engineering integration throughout the value chain to support product customization. Higher adoption levels of Industry 4.0 may be easier to achieve when lean production practices are extensively implemented in the company [27].

The research carried out also proposes a functional architecture with a minimum integration of Industry 4.0 paradigms to ensure the feasibility and flexible integration of the Lean 6S methodology in a digital environment, where order is guaranteed within the chaos caused by exponential growth of the contents.

Figure 1 shows the typical levels of the architecture of an intelligent system: the level of physical resources, the level of the industrial network, the level of cloud computing and the level of supervision and control terminal.

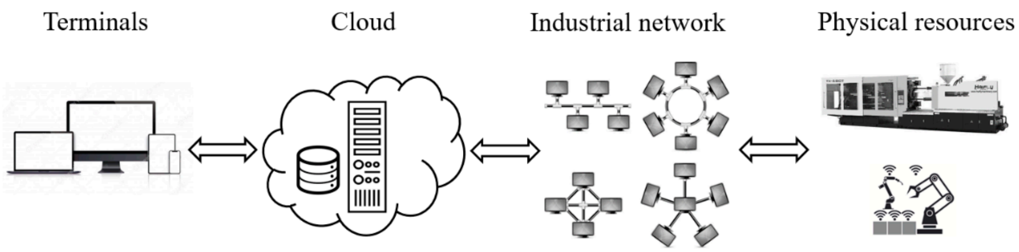


Figure 1. A brief framework of Industry 4.0.

Physical resources can communicate with each other through the industrial network. In the cloud, there are several information systems (e.g., CRM, ERP, PLM) that can collect massive data on physical resources' levels and interact with people through the terminals [28]. Intangible information flows freely thanks to a cyber-physical system (CPS), where physical devices and information entities are deeply integrated [29].

3. Results

Based on the proposed methodology, new flow diagrams have been generated in which the particularity of the type of resource in the workplace has been considered, so physical resources are clearly differentiated from digital resources.

The workflow review guarantees that, in the workplace, with respect to the resources used, a commitment to improvement is generated and decisions are made in accordance with the environmental management system and the digital information management model implemented.

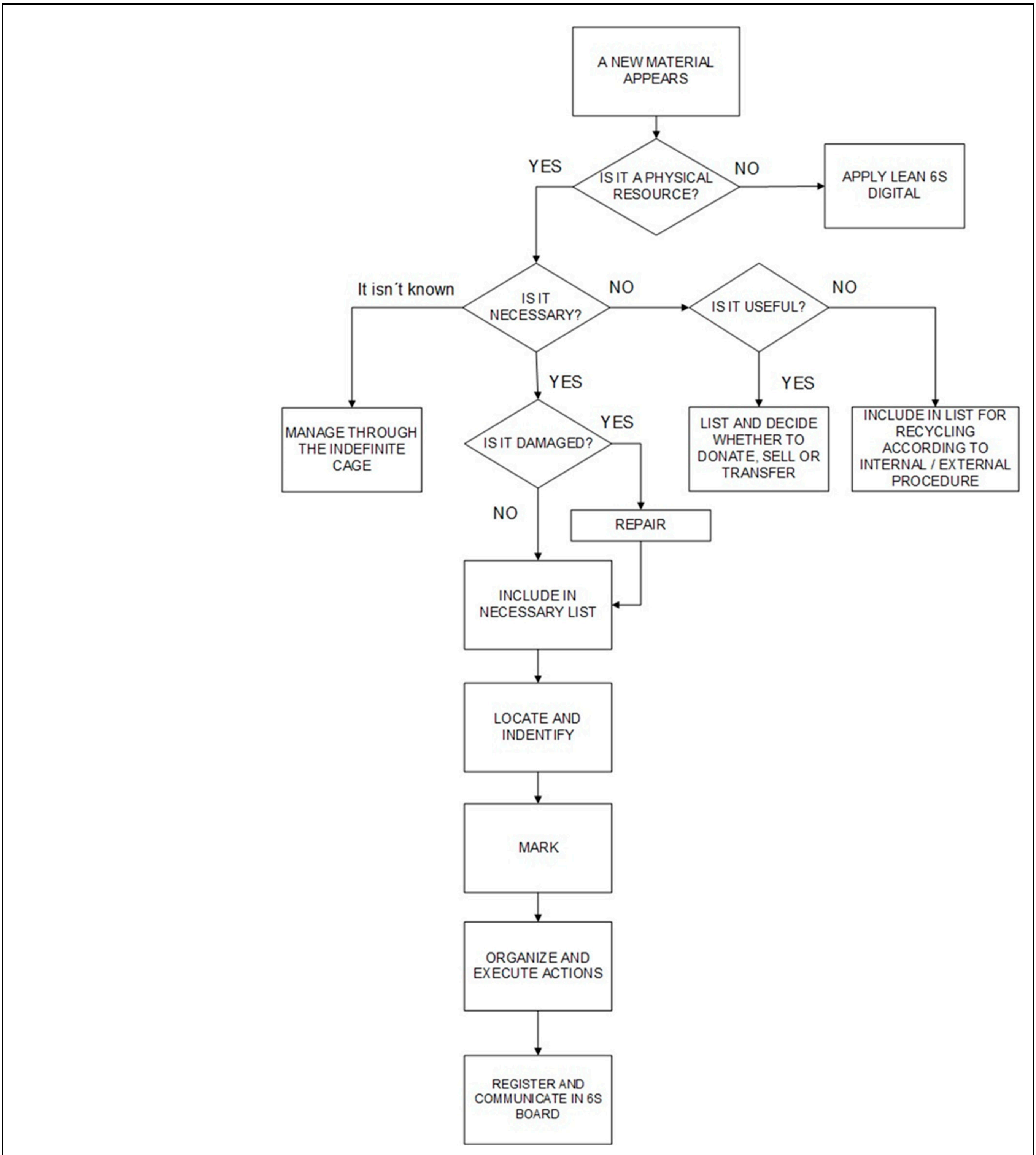
The digital 6S have been developed with a philosophy similar to the physical 6S. However, it is not a simple mimetic translation of the methodology, since physical and digital objects have particularities that differentiate them. The latter include in themselves metadata that allow an independent automatic organization of what the user decides regarding their identification [18].

The 1S-Seiri (remove unnecessary items) and 2S-Seiton (order necessary items) flowcharts are shown in Figures 2 and 3, respectively. These phases are the initial and the most important ones, since they establish the commitment towards the improvement of the job. It is in the second S where the difference in the organization of resources according to their nature is clearly observed. This treatment and reorganization of physical and digital resources minimizes the risk of a hidden disorder caused by the digital environment.

The diagrams for the 3S-Seiso (eliminate dirtiness), 4S-Safety (supervise safety), 5S-Seiketsu (signpost anomalies) and 6S-Shitsuje (continue improving) have been developed analogously to this approach.

The main recommendations for digital processing in the application of Lean 6S are as follows:

1. Remove unnecessary items:
    - Correctly define the necessary and unnecessary resources (files, emails, applications or other digital information objects). Assess obsolescence;
    - Use software to detect the amount and location (local network, hard drives, intranets, cloud storage, devices (laptop, tablet, smartphones)) of duplicate information, empty folders and old information;
    - Detect and identify the information to be processed: files, emails, applications, etc.;
    - Narrow the scope of documents to be explored;
    - Make backup copy prior to implantation;
    - Decide when and how (teams) the information will be processed;
    - Establish cage management criteria for doubtful information.
2. Order necessary items:
    - Define how documents/information should be located and identified;
    - Identification: name of the document, tags or metadata that help to locate it and describe the contents;
    - Coding needs to facilitate "unequivocal interpretation" of content;
    - Do not overcomplicate the folder/subfolder tree. Coding can help eliminate levels.
3. Signal:
    - Explain what is contained in each storage area (folders and documents) and how it is managed;
    - Maintain an updated manual where the criteria for grouping and identification are explained.
4. Continue improving:
    - Guarantee that the system will be maintained over time;
    - Explain the criteria to the team and review them from time to time with ongoing audits.
5. Indicators of the area after implantation:
    - Measure before starting the process. Indicators to measure the before and after;
    - Compare the number of necessary before and after.
6. Other general comments:
    - Analyze whether the data affected by the LOPD or other sensitive ones are well protected with robust management;
    - Describe the criteria for the location of the elements: what is contained on each storage location and how it is managed;
    - Identify and locate the elements according to the agreed criteria.



Sustainability recommendations ➔ Remove unnecessary items:
Definition of unnecessary: what is not used in tests or for maintenance.
Cage: open and controlled by the person in charge. It is not a warehouse of unnecessary. Monthly review.
Decide utility by consensus. Collegiate decision to establish the final profit.
Assign and ensure recycling according to regulations and defined procedures.

Figure 2. Traditional classification procedure for 1S-SEIRI/2S-SEITON with sustainability criteria.

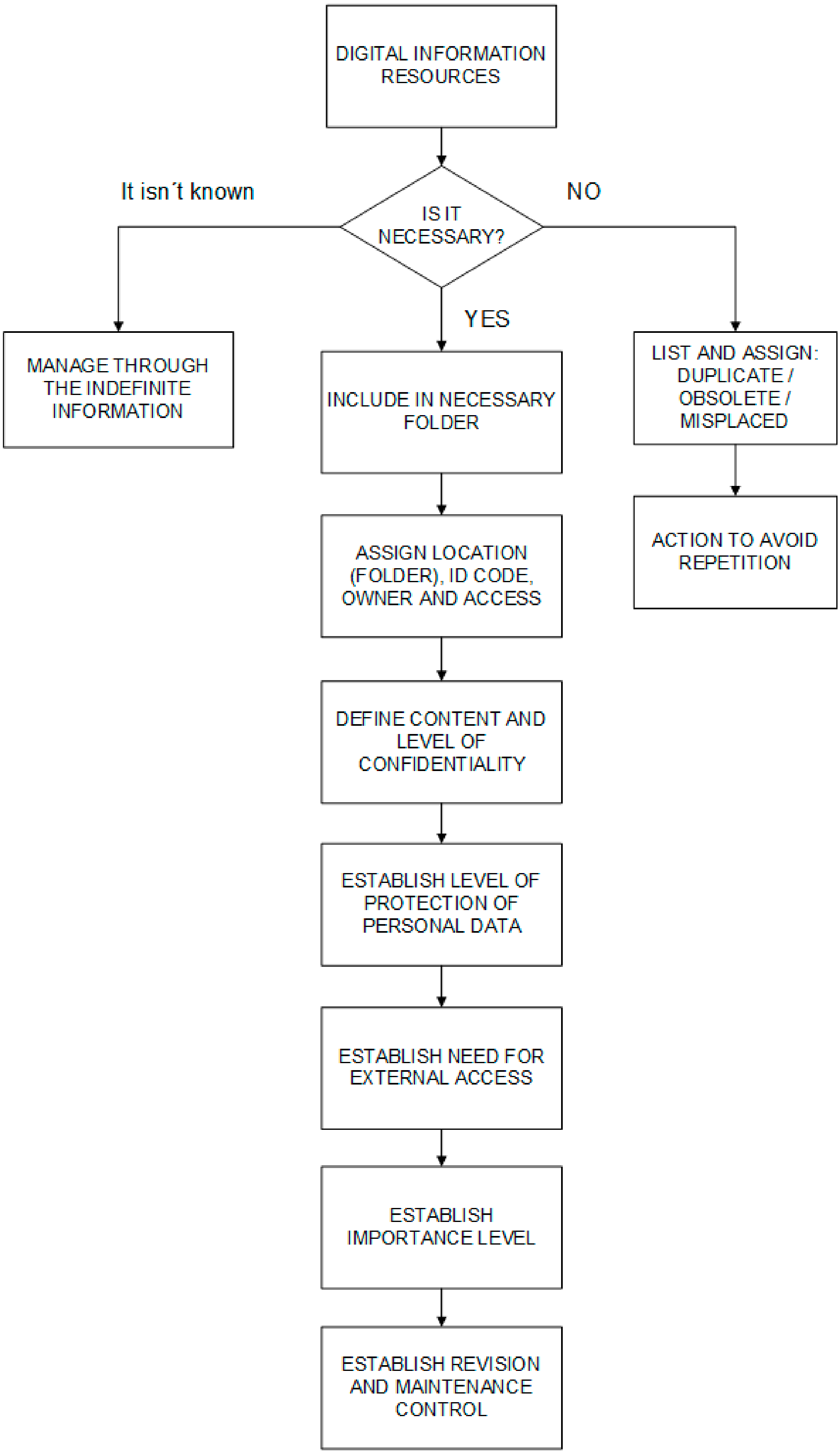


Figure 3. Digital classification procedure for 1S-SEIRI/2S-SEITON with digitization criteria.

The expected results of the review of the Lean 6S methodology with sustainability and digitization criteria are the following:

- Saving time in workplace operation;
- The improvement of environmental performance through the control of materials in the workplace;
- Compliance with legal requirements and other environmental requirements inherent in the generation, emission or discharge of any type of pollutant or waste;
- Control of the overabundance of digital information to eliminate problems in locating content;
- Improvement in the organization of digital information supports and the use of electronic messaging and document management resources;
- Facilitate access to information on the go;
- Computer security is the guarantee of the procedure;
- Establishment of a shared labeling structure for digital documentation;
- Reduction of computer security risks;
- Decrease handling errors;
- Saving physical storage space;
- Improved equipment performance;
- The generation of a level of efficiency in the information management;
- Waste reduction;
- Variation reduction in the processes and the products.

Based on the experience in the implementation processes of the Lean 6S methodology, it is recommended that the adaptation of the Lean 6S methodology with sustainability and digitization criteria to be carried out considers the following aspects:

- It is advisable to previously experiment with the implementation of the traditional Lean 6S methodology;
- The implementation team must not exceed six people and must be assigned sufficient working hours;
- It should start with a simple pilot area of guaranteed success, with a well-defined scope;
- The selection of a coordinator of the implementation process with knowledge of the processes to be evaluated and with ICT knowledge, environmental management and data processing;
- The training of the implementation team in the management of basic computer tools for the use and organization of information files. Try to know previous experiences of implementing Lean 6S in an office environment (Lean Office);
- The incorporation of a worker with advanced knowledge in ICT and another with responsibility for the environmental management system to the implementation team;
- The selection of the pilot area with traditional physical resources and the influence of global digital information, where the probability of success is high, to provoke motivation and interest in the environment;
- Integration in the first and second phase of environmental management and digital control criteria;
- Review of waste treatment procedures in the third phase;
- Integration in the fourth phase of computer security and environmental security criteria;
- Extension of the fifth phase to visual management through screens or adapted peripherals;
- Review of the sixth phase regarding the process of conducting audits, integrating new digital tools to eliminate the cause of a non-conformity and prevent it from happening again. It is necessary to ensure that the new standards are selected by its advantages: simpler structures to organize the information, less volume of data and more descriptive identifications, all of them to achieve an improvement in productivity;
- The handling of large volumes of data through big data dynamics can cause confusion with the Lean 6S mentality, which is focused on eliminating the unnecessary. Therefore, a detailed prior analysis of the functionalities of digital paradigms is required to guarantee the balance between the impact of algorithms and artificial intelligence with human intervention [20].

As mentioned in the methodology, one of the objectives of this research is to focus on the definition of a basic architecture for the intelligent implementation of Lean 6S and the operational organization of all the components involved: cloud computing, intelligent plant devices, physical resources, etc. A vertical integration is proposed within the company that serves as the basis for the integration of the entire life cycle process of our product or service.

In companies, the use of different physical and informational subsystems that must be integrated to obtain a flexible and dynamically reconfigurable system is frequent. The definition of this architecture allows the adaptation to any activity in a transparent way.

In this environment, the conditions for adaptation to architecture that must be defined by the ICT area would be the following:

- Which tools (software and hardware) are to be used during the implementation;
- The necessary and unnecessary resources (files, emails, applications or other digital information objects);
- A software to detect the amount and location (local network, hard drives, intranets, cloud storage, devices (laptop, tablet, smartphones)) of duplicate information, empty folders and old information;
- A backup prior to implementation;
- Management of the location, identification and information coding;
- A robust management of the data affected by the LOPD or other sensitive ones.

A proposal for the digital integration of the Lean 6S methodology in a functional software and hardware architecture would is shown in Figure 4.

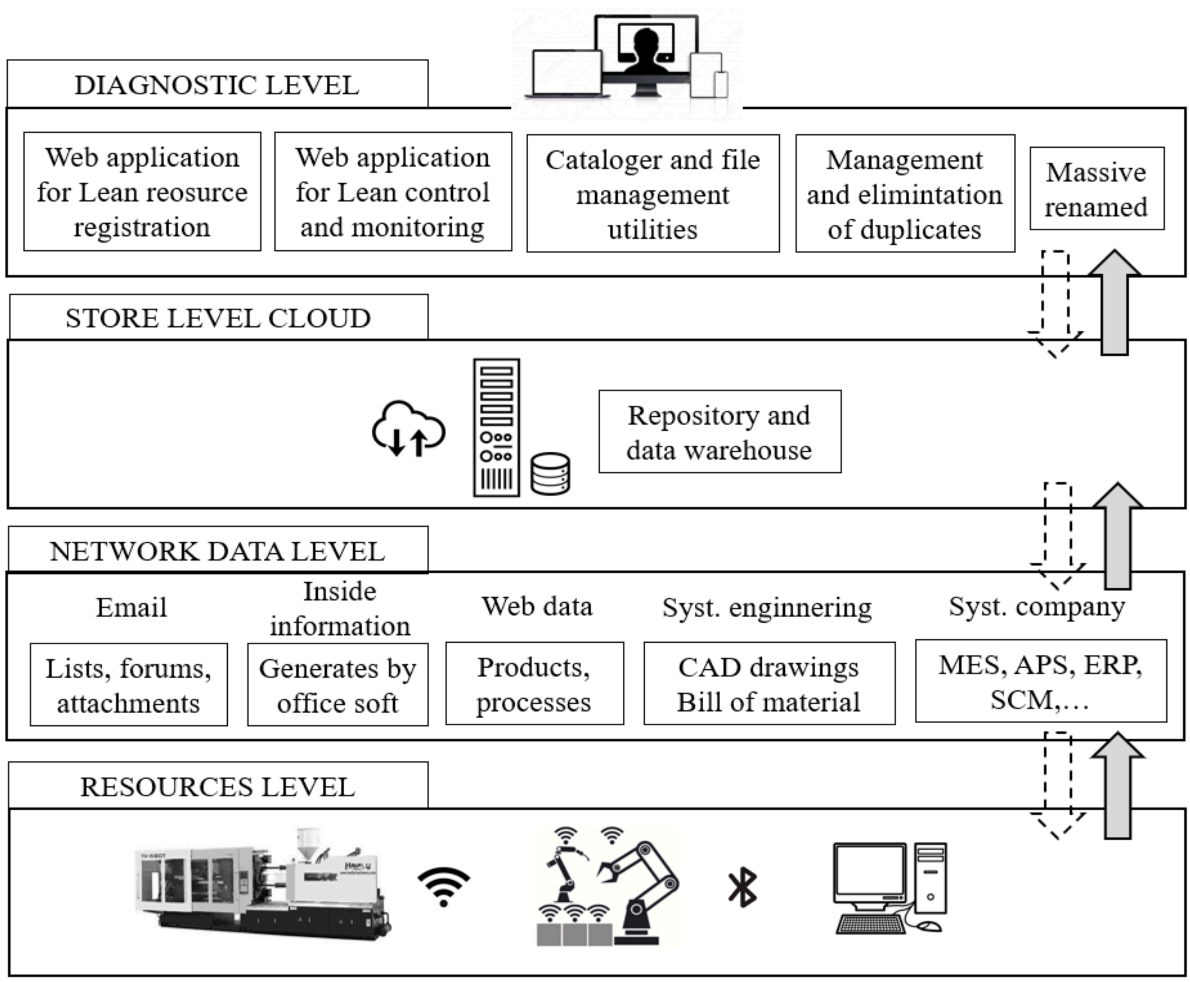


Figure 4. Layered functional architecture for Lean 6S implementation and control.

A versatile and widely known architecture based on levels or layers is proposed [30]. This pattern is characterized by its simplicity and is ideal as an initial implementation proposal since it allows separating the different roles and necessary resources. Its main characteristics are as follows:

- Each level has a degree of independence and responsibility since it has very defined functions. It is the ICT area that must set the flow of communication to ensure order between the levels;
- Each level can be tested individually;
- Maintenance is easy as the source of errors is quickly identified for changes, allowing for continuous operation;
- To avoid cyberattack problems, security can be accomplished by isolating servers on different subnets;
- Four levels are established: resources, network data, storage and diagnostics;
- Resources' level. It comprises various types of physical devices such as products and machines that can communicate with each other over the industrial network and collaborate to achieve a goal throughout the system;
- Network data level. It forms a kind of important infrastructure that not only allows communication between devices but it must also be able to connect the physical resource layer with the cloud;
- Storage level. Cloud. Network of servers that provide layered services in the form of infrastructure to control and virtualize a huge pool of resources. It facilitates the future application of big data because both storage space and computing capacity can be scaled on demand;
- Diagnostic level. Terminals. Links people to the company. With terminals such as PCs, tablets and mobile phones, workers can access the data provided, apply different settings or perform maintenance and diagnostics, even remotely via the Internet.

Depending on the data processing degree and resources growth, the scalability of this architecture should be reviewed because the dependence on communication between the levels with proprietary technologies or the control of failures in the event of a problem at a certain level, could cause problems that must be optimized.

The penetration of new technologies in an industrial environment that favors data management is associated with the use of mobile terminals and broadband integrated in the cloud. The Lean 6S methodology in a digital environment requires a relationship with software based on an agile and easy service so that workers can adapt to the needs of their application.

Workstation virtualization offers a more homogeneous environment by being able to work from different terminals. It is easier to manage and is safer and faster to restore. To guarantee 100% availability, easy access is required anytime, anywhere and is achieved with the web service.

It must be noted that these solutions provide a commitment towards sustainability (Green IT) thanks to the reduction of energy costs of monitoring devices connected to the network, thanks to energy savings through the jump to the cloud, and optimization of its life cycle [31]. The intelligence of the data also has its Lean impact, since it generates reports that help to optimize the results, the procedures used, and the use of the resources.

4. Discussion

Nowadays, the socioeconomic trends are forcing the projection and modeling of the factory of the future. Due to the scarcity of resources and raw materials, the environmental impact and the penetration and availability of new technologies, a review of the Lean 6S methodology with Industry 4.0 and sustainability commitments is proposed. This review requires the contribution of people with ICT and environmental management skills, without forgetting the recognition of the work of the implementation team and the allocation of the time necessary for the implementation and the audit process.

The use of the PDCA cycle to achieve continuous improvement and adaptation of the Lean 6S methodology must also undergo an adaptation that allows the use of the potential of Industry 4.0 technologies. The collection of data to build a digital twin of the workplace, will allow to detect critical points and a subsequent intelligent diagnosis that helps us to improve the planning, monitoring and standardization of activities in the workplace [21].

The current literature claims the direct effects of Industry 4.0 technologies (I4T) on lean manufacturing practices (LMP) and sustainable organizational performance (SOP) [5]. Higher adoption levels of Industry 4.0 may be easier to achieve when lean production practices are extensively implemented in the company. On the contrary, if the processes are not solidly designed and continuous improvement is not used, companies have more difficulties to implement new technologies [29].

In an intelligent manufacturing environment, the architecture of the Lean 6S methodology implementation model must be based on the accumulated knowledge and analysis of the performance of the manufacturing cycle processes, to generate information (indicators) in real time that guarantees execution of activities linked to sustainability and the correct treatment of information [32].

Companies that have Lean methodologies and techniques implemented have foundations that facilitate the connection with Industry 4.0 technologies. The Lean principle of avoiding waste is associated with the optimization of digital information through the cloud and the principle of zero defects with the treatment of big data through big data [18].

The proposed Lean 6S methodology can be used as a connection base with Industry 4.0 using cloud computing, mobility, IoT and big data technologies, which will facilitate the capture of data in the workplace, its storage, treatment and consultation for decision making. The worker must be able to navigate, technically and through the contents, and must organize, focus and transform that information into concrete knowledge that is useful for their work.

The systematic review of digital information provokes a new culture around the efficiency in the use of digital data and the tranquility of the information processing and the responsibility of safe environments. The big data paradigm is adapted, thanks to the revision of the digital 6S, into small data, where the control and optimization of digital information predominates [20].

In addition to other similar studies in this area [15–17], the critical success factors detected in this study regarding the implementation of digital Lean 6S are the following:

- Involvement of the Management and the ICT area;
- Project planning;
- Strategic relevance;
- Commitment and advanced training of the team;
- Adequate pilot area;
- Plan to advance the extension of the implementation;
- Agile audits;
- Tangible results.

The revised Lean 6S methodology must be supported by a structure and technological tools that guarantee the automation of information handling routines, but especially, it must be effective in the correct implementation and obtaining of results [23,32]. A structure based on layers or levels is proposed due to its widespread use and easy implementation.

The research team is currently carrying out different implementation processes of the adapted Lean 6S methodology. Updated questionnaires and checklists based on previous research are being used [33–35]. This prior audit in the areas of implementation is allowing users to detect the previous level of Lean knowledge and the application of sustainable practices. With this verification, it is possible to optimize the implementation of the adapted Lean 6S methodology and guarantee its success thanks to the tailor-made planning and training of the implementation team.

5. Conclusions

The application of the adapted Lean 6S methodology contributes to sustainable development and a commitment to economic and environmental sustainability thanks to the reduction in energy costs and the control of the deterioration and efficient use of resources. It must be considered that when a minimum standard of commitment to sustainability is reached in the work environment, there is a basis that favors the development of social sustainability in other areas.

Before implementing Lean 6S with a digital approach, the implementation of the traditional Lean 6S methodology (physical) is recommended to previously create in the workplace a way of thinking and reflecting and a vision that facilitates innovation towards digitization.

The next steps of this research will focus on the implementation of the methodology in environments where the existence of physical and digital resources allows verifying the scope and results of the proposed adaptation.

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