Increased Capacity in Industrial Equipment

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Abstract

This article discusses the application of continuous improvement tools in an aeronautical company. The main goals are to enhance equipment availability and efficiency, leading to improved Overall Equipment Effectiveness and reduced energy costs. The focus is optimizing specific equipment with lower productivity due to limited data and documentation. The process at different workstations is analyzed, and data is collected to apply lean tools, aiming to increase efficiency by 10% and optimize the equipment's productive capacity by 20%.
The article explores the fundamentals of lean, originating from the Toyota Production System, which seeks to eliminate seven types of waste. Several lean tools such as Single Minute Exchange of Die, 5S, and Standard Work are utilized. Additionally, kaizen practices like cross-functional teams, decentralized responsibilities, the pull system, and Just-in-Time are employed to complement Lean Manufacturing. The implementation process follows the Plan-Do-Check-Act methodology, supported by the Hoshin Kanri methodology, allowing for the proper sequencing of actions and validation of achievements. Furthermore, the article touches upon the evolution of the aeronautical industry and its relationship with lean practices to establish relevant correlations.
Through the application of these methods, it was considered, based on the data obtained in the initial diagnosis, an increase of 17%, 55% and 31% in the efficiency of setups in autoclaves, computerized numerical control machines and ultrasound, respectively, which in all exceeded the goal of 10%. As for the increase in equipment availability, relevant results were also obtained compared to the 20% target, having reduced about 45h/year in autoclaves in two cycles along with a gain of 19% in the occupancy of the surtec.

Keywords
Aeronautic Industry; Continuous Improvement; Lean Manufacturing; OEE; SMED.

1. Introduction

The aviation industry holds great importance for countries due to its technological and innovative nature, which positively impacts the economy. Beyond economic benefits, aviation also brings significant societal advantages by revolutionizing perceptions of time and distance. Aeronautics represents the epitome of manufacturing, generating skilled jobs and driving industrial development and technological innovation. Forecasts indicate constant growth, establishing the aeronautical sector as a strategic economic, social, and cultural activity in Europe and the USA (Fujita 2010).

As the industry expands, globalization is evident, with a strong focus on meeting customer expectations. Factors such as quality, cost, variety, and speed of delivery play vital roles in distinguishing competitors. Consequently, modern industrial environments prioritize flexibility and efficiency to minimize wasteful activities that lack value generation (Godina et al. 2018).

However, adapting to these changes can present challenges, particularly regarding production processes that involve non-value-added operations that are nevertheless essential for production (Silva et al. 2020).

In response to these demands, a study was conducted in an aeronautical company to enhance production equipment availability, production capacity, and setup time reduction. Additionally, the study addresses the need to lower energy costs, considering the escalating expenses in Portugal.

1.1 Objectives

The study aims to improve the production capacity of industrial equipment to achieve a production improvement according to the following intermediate objectives: 20% improvement in equipment availability; 10% improvement in setup efficiency; Reduction of costs associated with energy; Measurement and verification of process times.

Having said this, the following hypotheses were formulated: How do lean practices affect equipment availability and setup efficiency? How can continuous improvement tools be applied to reduce waste and process variability along the production line to reach the desired productivity levels?

2. Literature Review

This chapter covers several themes and concepts that are fundamental to the empirical basis of the project. It begins with a context about the evolution of the aeronautical industry, followed by an analysis of the Lean concept, from its origin to its current philosophies, as well as the tools and methodologies that come from it, such as the Single Minute Exchange of Die (SMED) and the OEE.

2.1 Aeronautical Industry

The aeronautical industry is a significant economic sector characterized by high technological levels, innovation, and long-term investment returns (ECORBYS 2009). It encompasses various sectors and contributes to the creation of high-skill jobs. Demand for the industry is expected to grow, as aircraft manufacturers rely heavily on the air transport and airport sectors (OCDE 2020).

The European Union is a leading producer of civil aircraft and related components, employing a substantial workforce and generating significant revenues and exports (European Commission 2019). To maintain European leadership in aeronautics, the European Vision for Aeronautics and Air Transport was launched, leading to the formation of ACARE to define a strategic research agenda (Fujita 2010). However, the industry has faced downturns in recent decades, including events like the September 11 attacks, the financial crisis of 2008, and the COVID-19 pandemic. The pandemic resulted in a significant decline in passenger-kilometer revenue and disrupted global air travel (IATA 2020; International Air Transport Association (IATA) 2011; Ito and Lee 2005).

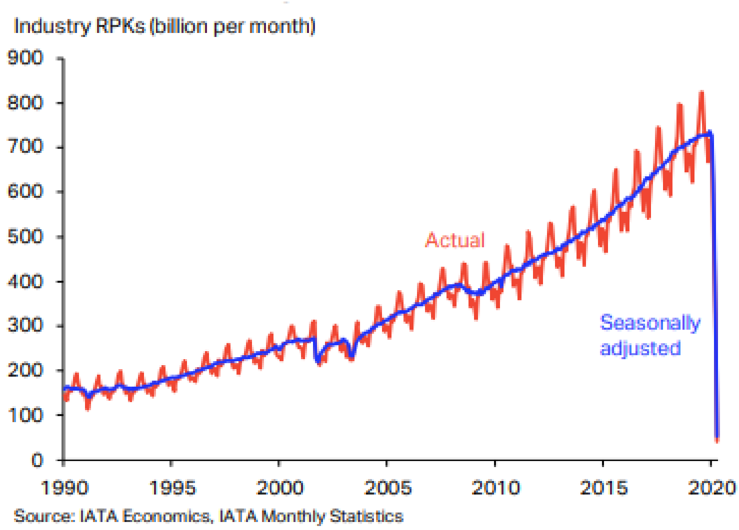

Figure 1. Air passenger volume (IATA 2020)

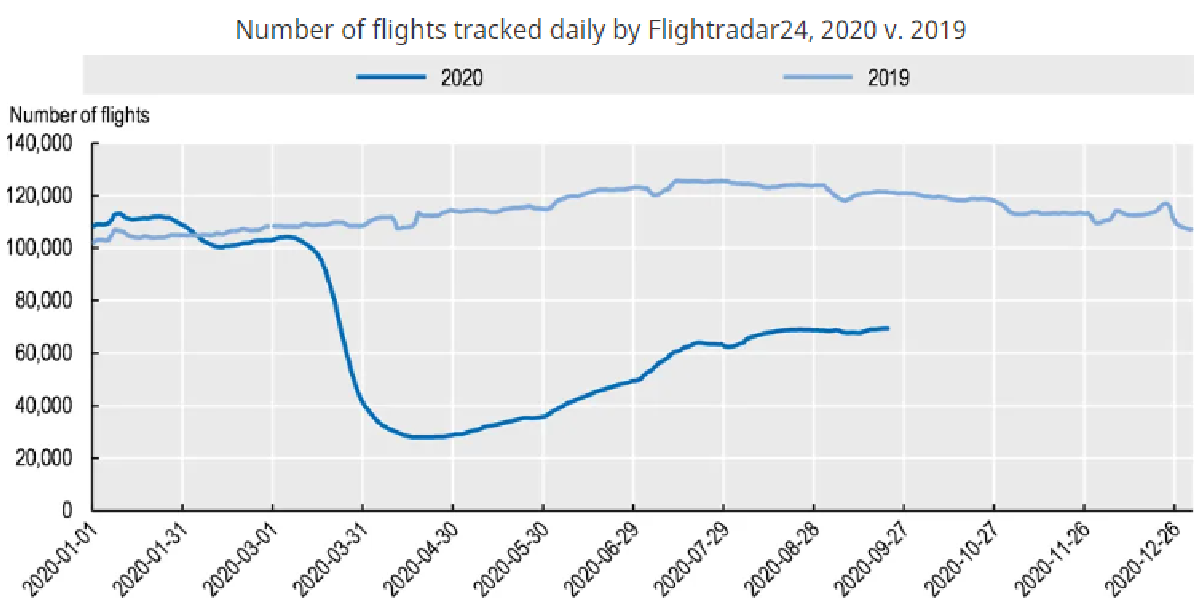

Figure 2. Number of flights in 2019 vs. 2020 (OCDE 2020)

Despite these challenges, the industry is projected to grow due to its emphasis on technological innovation. However, this growth is contingent on various external factors, such as societal development, population growth, energy resource utilization, future business models, and evolving lifestyles (AgustaWestland 2014).

2.2 Aeronautical Industry in Portugal

The aeronautical industry is identified as a priority development area by the Portuguese government, as stated by the Portuguese Agency for Investment and Foreign Trade (AICEP). To support its growth, the industry requires advanced technologies, manufacturing capabilities, and the development of systems and maintenance. Portugal benefits from excellent engineering schools, qualification programs, and active participation in international aerospace research and innovation programs such as the European Space Agency (ESA) and the European Aviation and Safety Agency

(EASA). Involvement in renowned global aeronautical programs like the Embraer KC-390, AgustaWestland AW609 tiltrotor, and EADS-CASA C-295 further contributes to driving growth.
Additionally, Portugal has been involved in a winning project for the visionary concepts category at the Crystal Cabin Awards 2012. This project focuses on creating eco-efficient, lightweight, and comfortable aircraft interiors with innovative designs. Collaboration among companies such as Douro Azul, SET, Amorim Cork Composites, and the institution INEGI, along with the participation of Almadesign and Embraer, plays a crucial role in this initiative (AICEP 2013).

2.3. Lean Production

The term "Lean" was introduced by (Krafcik 1988), originating from a study comparing Japanese and American automotive production systems. It emphasized the importance of reducing stocks and excess workers, as opposed to the buffered approach of other manufacturers (Hopp and Spearman 2004). In 1996, the term evolved into "Lean Thinking" through further studies, which highlighted the need for Lean implementation across various business areas (Womack and Jones 1996).
Lean Thinking views waste as any activity that does not add value to the product and is guided by principles such as identifying value, eliminating waste, and creating a value process for the customer (Melton 2005). At the strategic level, Lean principles can be categorized into five areas: value, value stream, flow, pull, and perfection. Lean Production encompasses Lean Development, Lean Procurement, Lean Manufacturing, and Lean Distribution, with Lean Manufacturing being particularly emphasized (Staats, Brunner, and Upton 2011).
In view of this, (Karlsson and Hlström 1996) allude that the Lean Manufacturing methodology offers multifaceted concepts that can be applied in various areas, making it widely adopted by companies across industries to maintain competitiveness and improve results. According to (Ohno 1988) it involves practices such as waste elimination, continuous improvement, cross-functional teams, zero defects (Just-in-Time), vertical information systems, decentralization of responsibilities, and the pull system. These practices work together to eliminate the seven types of waste: overproduction, defective products, waiting times, unnecessary transportation, excess stock, overprocessing, and unnecessary movements. Work in Progress (WIP) is identified as the primary source of waste in the Lean Manufacturing philosophy.
The study by (Shah and Ward 2003) supports the existence of Lean Manufacturing (LM) bundles, which include Just-in-Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM), and Human Resource Management (HRM). These bundles share goals related to continuous improvement and waste reduction.
HRM, as part of the LM approach, focuses on functions such as multitasking, hierarchical organizational structure, and employee motivation. These practices and principles of LM, including JIT, TQM, TPM, and HRM, contribute to improving organizational performance. Additionally, Lean Maintenance is considered a prerequisite for these systems and is regarded as a key pillar of overall organizational performance (Demeter and Matyusz 2011).
Nowadays, the integration of Industry 4.0 with Lean Manufacturing, denoted as Lean Automation (LA), is widely addressed as it is considered very useful for companies to integrate LP tools with Industry 4.0 tools, as it allows them to improve Standard Operating Procedures (SOP). This integration will accelerate the development of optimized systems in manufacturing companies, reduce the costs of implementing Industry 4.0 tools, and aims at greater changeability and shorter information flows to meet future market demands (Gallo et al. 2021; Mrugalska and Wyrwicka 2017) .

2.4 SMED

The Single Minute Exchange of Die (SMED) methodology, developed by Shigeo Shingo, aims to reduce setup times in production processes (Van Goubergen and Van Landeghem 2002). It can be applied across various industries and involves five steps: work study, separation of internal and external work, transformation of internal work into external work, reduction of internal work, and reduction of external labor (Almomani et al. 2013). Implementing SMED offers benefits such as increased production capacity, improved quality, reduced waste, enhanced flexibility, and cost savings. SMED emphasizes performing tasks simultaneously with equipment operation to minimize downtime during changeovers. It is possible to achieve a 90% reduction in setup times with a moderate investment. The use of Multiple Criteria-Making Techniques (MCDM) is suggested to improve the selection of techniques during SMED implementation, considering factors like cost, energy, layout, quality, and maintenance, to optimize the setup process.

2.5 OEE

Overall Equipment Effectiveness (OEE) emerged as a quantitative metric, from the concept of Total Productive Maintenance (TPM) launched by (Nakajima 1988), to measure the productivity of manufacturing equipment.

It identifies and measures losses in equipment availability, performance, and quality with the aim of improving equipment effectiveness and productivity. These losses are activities that absorb resources but do not create any value (Pintelon, Gelders, and Puyvelde 2000).
According to (Jonsson and Lesshammar 1999), losses originate from either chronic or sporadic disturbances. Chronic disturbances are often covert and have concurrent causes. In contrast, sporadic disorders are noticeable because they occur suddenly and cause major deviations from the usual state.
However, according to the literature, OEE measures the degree of conformity of process outputs with requirements, i.e., effectiveness. As opposed to efficiency, which is the degree to which the process produces the required output at minimum resource cost (Muchiri and Pintelon 2008).
The calculation of losses is measured using the OEE, see equation 1:

$$OEE = Availability\ (A)\ \times Perfomance\ (P) \times Quality\ (Q) \qquad (1)$$

Each component of the OEE is calculated by equations 2, 3 and 4, respectively:

$$A = \frac{Operation\ Time - Planned\ Downtime}{Time\ Available - Time\ Unplanned\ Production} \qquad (2)$$

$$P = \frac{Ideal\ Cycle\ Time}{TTheoretical\ Cycle\ Time} \qquad (3)$$

$$Q = \frac{Number\ of\ Compliant\ Units}{Total\ units\ produced} \qquad (4)$$

3. Methods

The adoption of methodologies requires a prior study of the processes on which the study is focused, through the monitoring and observation of these on the shop floor and the performance of a Literature Review to deepen the theme. This way, one acquires a good know-how of the practical and theoretical component necessary to choose the best methodology to adopt, following an abductive approach, which combines the deductive and inductive approaches. This begins with the observation of a situation for which, later, an explanatory theory is developed through creativity and innovation.
As such, and to achieve the objectives set out, the PDCA methodology was used, which is divided into four phases: Plan, Do, Check, Act, based on the Hoshin Kanri methodology.

4. Data Collection

For the study some workstations were selected that were subject to analysis, according to the production flow: Autoclaves, Computer Numerical Control (CNC's) and Ultrasounds. The selection of these was made by the company according to its needs. In general, these had no historical records and represented delays in production, which motivated their study.

4.1. Autoclaves

Starting with the autoclaves, which is a process of waste and porosity elimination in which aircraft structural parts made of composite materials are exposed to high temperatures and high pressures in an inert atmosphere, it began by studying the programs covered by each cycle and the respective parameters. In addition, with a view to increasing the efficiency of the setups, a study of methods and time was carried out, following the entire loading/curing, and unloading process of each cycle, from which improvement actions emerged.
As for the occupancy/availability of autoclaves two approaches were defined: cycle occupancy vs. number of valves and thermocouples available; curing cycle time per program. These resulted in actions such as the definition of new layouts for the cycle occupancy of some programs and the reduction of cycle times of two programs, which consequently causes a reduction in nitrogen costs.

4.2 Surtec

Surtec is the oven that assists the demolding workstation, when they do not demold the parts after the end of the autoclave cycles, having the need to heat the molds again before demolding them. In addition, sometimes there is also the need to heat molds to enter layup.

From the diagnosis it was found that the main problem was related to the occupation of the oven, so vertical carts were developed for demolding and double vertical carts for layup, Figure 3. At the same time, a planning for the heating of molds that go to layup was implemented.

Figure 3. Surtec's Current Occupancy vs Dual Cars vs Vertical Car

4.3 Ultrasounds

The automatic inspection process is carried out using an ultrasound system that allows the inspection of a certain family of parts to identify internal non-conformities.
For this, the company has a vat, divided into three phases, to perform the inspection of parts of different programs. Thus, it was decided to adopt the SMED methodology starting with the chronometric registration, advancing to the separation of internal work from external work, with a view to the possibility of transforming internal work into external work. Finally, it was projected the reduction of both internal and external work with the implementation of some actions.

4.4 CNC's

In the CNC workstation we studied essentially the CMI machine where a study of methods and times was carried out for the TEP program, the only one currently cutting. However, the company was preparing to introduce the cutting of a new program, so it was proposed to develop a man-machine diagram to analyze how to introduce the new program, along with identifying the unproductive time. In parallel, it was planned to develop actions based on the 6S methodology to eliminate unnecessary materials, to clean and tidy the workplace, and to standardize the sequence of process steps. Through the diagram developed for initial diagnosis it was found a high inefficiency so another one was developed after the development of actions that allowed to evaluate an increase of 40% with these implementations.
For all CNC machines a standard work of the tasks was also developed.

5. Results and Discussion

5.1 Numerical Results

At the beginning of the article, the research question raised was essentially based on the evaluation of continuous improvement tools that could reduce waste, minimizing setup times and equipment availability, as well as the creation of a standard of operations associated with them.
In this sense, Lean tools and methodologies were applied, such as SMED, Standard Work 5S, and VSM, which allowed, based on the Kaizen culture, to achieve the proposed objectives.
To proceed to the discussion of the results we recall the starting point in which the objective was to increase equipment availability by 20% and improve setup efficiency by 10%. Based on this, and using the actions developed at each workstation, detailed in the previous chapter, an overall analysis of the results obtained was performed and Table 1 was drawn up, which visually represents the workstations that achieved the purpose, in green, and in yellow, those that came close to achieving the desired goal.

Table 1. Results obtained at each workstation

Objective	Equipment	20% Increase in Availability	10% Increase in Setup Efficiency
Results	Autoclave	45h/year	17%
	Surtec	41%	-
	CMI	39%	32%
	Ultrasounds - Phase 1	Future Work	5%
	Ultrasounds - Phase 3	Future Work	26%

The project has been successful in most areas, with planned long-term improvement actions yielding significant gains. For instance, extending the rails of the autoclaves is estimated to save 201 hours per year by facilitating car movement and allowing for an increase in the number of cars loaded simultaneously with curing cycles, aligning with the SMED methodology.

In the case of Surtec, the goal was achieved by optimizing the occupancy, which resulted in a 41% increase over the initial occupancy, allowing it to reach 98% of its maximum capacity.

The results regarding the CMI occupation suggest the development of a new man-machine diagram, where it is possible to verify a significant increase in the availability of the machine and of the operator, in shift 2, where it is possible to verify that his occupation has become practically null. From this, the expansion of a new action plan is being considered, in a future phase, that reduces the occupation of both the operator and the machine by another 6 to 7%, with the intention of eliminating this shift and thus reducing costs. However, considering the current scenario achieved, the success of the planned actions is acknowledged, having achieved what was proposed.

The ultrasound workstation posed challenges, particularly in terms of availability, due to the complexity and cost of making airtight layout changes during production months.

Overall, and taking into consideration the complex and variable nature of the line's production, coupled with the introduction of new programs, required a different approach to analyzing production flows and implementing actions. Despite these challenges, the application of Lean tools and time study methods enabled a positive overall intervention in production, uncovering previously hidden sources of waste.

5.2 Graphical Results

Evaluating the actions developed in the autoclaves, regarding the efficiency of the setups, and considering the goal of 10% increase, we can conclude that this was achieved in the programs analyzed, resulting in a reduction of 284 h/year. This gain can be evaluated, per program, in Table 2 and Figure 4.

Table 2. Gains Load/Unload autoclaves per program

	Time (min)									
Program	Load	Load Reduction	Load Reduction (%)	Discharge	Discharge Reduction	Discharge Reduction (%)	Total	Total After Improvements	Total Reduction (%)	Reduction/ year
PT AU09	116,20	10,88	9,36	97,17	7,69	7,92	213,37	194,80	9%	891,2
PT AU02	73,57	7,29	9,91	57,57	11,85	20,58	131,13	111,99	15%	9188
PT AU04	76,85	7,73	10,05	35,07	3,42	9,74	111,92	100,78	10%	1069,6
PT AU01	-	-	-	61,60	14,70	23,86	61,60	-	-	5913,6
									Ganho Total	284,37

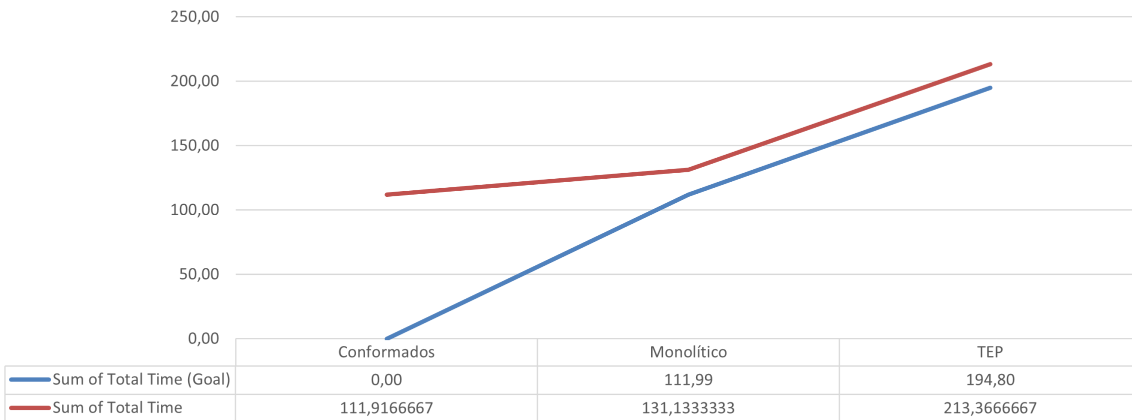

Figure 4. Current Charge/Discharge Time vs. After Improvements

5.3 Proposed Improvements

Following the diagnosis made to the ultrasonic verification station resulted in several improvement actions for Phases 1 and 3, which, supported by the time study, it was possible to estimate the gain with these implementations, Table 3.

Table 3. Improvement Actions Ultrasound

Problem	Indicator	Corrective Action	Gain
Poorly functioning tools for loading/unloading - Phase 1	Time	Create a tool with an adjustable handle to carry any part.	10,77min/ inspection
Difficult to perceive the limits of the bowl usable area - Phase 1	Time	Outline on the tub glass the limits.	1min/ inspection
Cleaning the Parts - Stage 1	Time	Alert demolding due to poor cleaning of the parts.	1,67min/ inspection
Wasted Moves - Phase 1	Time	Place a computer on the bench by the vat to record production orders.	1,20min/ cycle
Placement of the standards in the vat at each inspection - Phase 1	Time	Apply sealant to the patterns and leave them permanently in the tub.	1,5min/ inspection
Duplicate Picking of POs	Time	Completing the layout document from the pick in SAP.	10min/ inspection
Redução do tempo de setup internos (máquina parada) – Fase 1	Availability	Division of the vat by sections, in phase 1, to reduce inspection time and make it possible. to load/unload the others at the same time.	50%

Má ocupação da área útil da cuba – Fase 1	Occupation	Make changes to the part positioning layout.	10%
Travel to pick up parts	Time	Place carts with the parts next to the workstation.	1,89min/ inspection
High time for part positioning - Stage 3	Time	Create a layout for the positioning of the pieces.	5,79min/ inspection
Long time to align nozzle jets	Time	Arrange mechanism to align pressure of the two mouthpieces.	1,5min/ inspection
Definition of coordinates at each inspection	Time	Fix coordinates in the vat and set coordinates.	8,87min/ inspection
Induced Defects and Parts Cleanliness	Time	Reduce defects to one for each thickness; Use of pliers to cut defects in cork.	8,40min/ inspection

5.4 Validation

The purpose of the evaluation of the surtec was to optimize its occupancy, and taking into consideration that it was analyzed that its waste was in height, a vertical car and double cars were designed to increase occupancy.
Considering the dimensions of the greenhouse, 4 m x 3.25 m x 3 m, it has 69,5 m^2 of area and 38 $m^3$39 of volume, and according to the initial diagnosis, only 39,5 $m^2$and 6,74 m^3 were occupied, i.e., 57% and 17%, respectively, of its capacity.
With this as a basis, we designed a car with the dimensions of 2.31 m x 1 m x 2.66 m with the capacity to store 5 2.08 plates and double cars that allow the support of 2 2.08 plates.
From this and considering that there is no daily standard for the occupation of the surtec, three possible scenarios were created, and the situation observed in the initial diagnosis was compared with the diagnosis of the current situation after the improvement implementation, Table 4.

Table 4. Surtec Occupation Scenarios

Initial Diagnosis	**Current Diagnosis after improvement**	
3 plates 2.08 Demolding	5 plates	with Vertical Carriage (VC)
1 plate	8 plates 2.08 layup	with 4 Double Cars
2 plates	12 plates BBSS	with 3 Double Cars
Total: 6 plates	Total: 25 plates	VC + 7 Double Cars
OU		
3 plates 2.08 Demolding	5 plates	with Vertical Carriage (VC)
1 plate	6 plates 2.08 layup	with 3 Double Cars
2 plates	16 plates BBSS	with 4 Double Cars
Total: 6 plates	Total: 27 plates	VC + 7 Double Cars
OU		
3 plates 2.08 Demolding	5 plates	with Vertical Carriage (VC)
1 OMEGA	2 OMEGA	
2 plates	10 plates 2.08 layup	with 5 Double Cars
Total: 6 plates	Total: 17 plates	VC + 5 Double Cars

6. Conclusion

The work carried out included a study on the theme, which served as a basis for defining the objectives and the methodologies to be adopted. Following this, it was decided that the PDCA methodology, aided by Hoshin Kanri, would be ideal for a project that aims to improve the productive capacity of industrial equipment.

Furthermore, it was necessary to know the context in which the project would be developed and, as such, an analysis of the aeronautical industry and its evolution at a national and global level was performed. With that in mind, we proceeded to research about Lean and, more specifically, Lean Production and its evolution. In this sense, it was also essential to evaluate the appropriate continuous improvement tools to be applied in this context to increase the efficiency and availability of the machines. In addition, it was also intended to reduce energy costs.

In this way, a thorough study was done from the methodologies to be adopted, to the Lean philosophy and its tools that would then be implemented in the equipment identified as more critical to reduce waste, setup times and thus improve productivity.

Considering the methodologies and tools studied, the workstations were analyzed, and a correlation was established between their identified needs and the application method.

From this, multiple improvement actions were developed in the workstations previously defined. The best results came from the autoclaves, both in terms of the efficiency of setups and availability, where a reduction of 364h/year was totaled. In the CNC machines it also resulted in a significant improvement in efficiency and, specifically in CMI, a 39% increase in availability, which translates to almost a reduction of one shift. In this sense, it is pointed out for future work the reduction of another 6% of the machine occupation to grant this objective later outlined.

Overall, it is possible to conclude that the goals initially set were met, considering the data that resulted from the improvement actions implemented at each workstation. Simultaneously, a gradual increase in OEE is already perceptible in some posts, however, this indicator is not yet operational in all, since in the initial diagnosis the non-use of this indicator was identified, which made it impossible to use this indicator in most work posts.

However, considering the existing data and other indicators used, it is already possible to indicate that the improvements had a positive effect.

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