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Improving manual assembly lines devoted to complex electronic devices by applying Lean tools

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Abstract

Manual assembly lines are usually deeply studied before implementation. Nevertheless, several problems upsurge when the product needs to be slightly changed. This is very common in complex electric and electronic devices usually produced in small batches, where the customers are demanding more and more features and the product needs to be continuously updated. However, these updates sometimes create huge difficulties for the previously installed assembly line, generating as well, line unbalancing and wastes of time regarding the initial situation. In this paper, a deep study of an adjusted assembly line of electronic devices was carried out using Value Stream Mapping (VSM) method to fully understand and document the different tasks and operations. The Lean Line Balancing (LLB) was also applied in order to reduce the line bottleneck by balancing the Task Time (TT) of each workstation so that there are no delays, and nobody is overburden with their task. Standardized processes and standardized work were also applied. During the line layout development stage, assembly fixtures, wastes reductions and visual management techniques were applied as well, different concepts were generated and, finally, the best solutions were selected. Throughout the study, many benefits for the studied manual assembly line were found, which can be considered as a strong motivation to apply Lean Manufacturing (LM) tools for better line efficiency and production rate.

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Keywords: Manual assembly lines, Complex electric and electronic devices, Lean tools, Line balancing, Standard work.

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1. Introduction

Exposed to the global competitive pressure of continuously changing market conditions, more and more enterprises face the challenge to lower the production costs [1]. Nowadays, production paradigm is distinguished by an increasing product variety and assembly to ordered paradigm determined by lean principles [2-4]. Thus, assembly systems are today designed as manual assembly lines to produce several variants from a common product structure [5]. Several methods and approaches exist such as computer simulation, statistical analysis, and lean tools for improving the efficiency and productivity by determining the best combination of resources in production lines, construction process, energy, services and supply chains [6]. Lean production is one possible improvement strategy with which to address re-manufacturing challenges. Lean delivers a set of principles and tools to gain operational efficiency, reduce process waste, and increase productivity [7]. The majority of the studies focuses on single aspect of lean element, only very few focus on more than one aspect of lean elements, but for the successful application of lean, the organization has to focus on all aspects such as Value Stream Mapping (VSM), Line Balancing, Single Minute Exchange of Dies (SMED), visual management, Production Levelling, 5Ss, etc.[8, 9].

This case study was conducted at the Bosch Security Systems company, in Ovar. Therefore, the objective of this study is to illustrate how VSM, Lean Line Design (LLD) and other lean manufacturing techniques could improve the quality and performance of a complex manual assembly line, reducing production waste and manufacturing Lead Time (LT). The remainder paper is organized as follows: section 2 reports the literature review related to Lean Manufacturing; section 3 describes the problem formulation and the motivation to do it; section 4 describes the methodologies used, while Section 5 shows the proposed improvements to optimize one complex assembly line production, evidencing the results obtained. Finally, discussion and conclusions are dealt in Section 6.

2. Literature Review

This brief literature review approaches the Lean Production methodology, the VSM and the LLD (combines line balancing, layout optimization and workflow). These tools support the ongoing project and solutions to be developed.

Lean Manufacturing (LM) was developed by Toyota Motor company to address their specific needs in a restricted market in times of economic trouble [10]. Initially, before being applied in Toyota, in 1913, Henry Ford has invented Flow Production system, which is an integration of consistently interchangeable parts with moving conveyor belt and standard work [11]. It is generally agreed amongst researchers and practitioners that Lean was developed from the methods and working practices of the Toyota Production System (TPS) approximately in 1940, with its roots in the continuous flow thinking and moving assembly line concept of Henry Ford [12]. In 1990, James P. Womack, author of the book “The machine that changed the world”, set a milestone in the debate on LP (Line Production). In the last three decades, it is clear the numerous books and articles written by practitioners and consultants with the purpose of highlighting the overarching nature of LP. In figure 1 is highlight the key stages that have contributed to the evolution of Lean Production.

Lean manufacturing is a management philosophy in which the focus is on improving the work "flow" and its smoothness [13]. Basically, is a long-term philosophy of growth by generating value for the customer, society, and the economy with the objectives of reducing costs, improving delivery times, and increasing quality through the total elimination of waste, so that all time spent on the product is through value-added activities [14, 15].

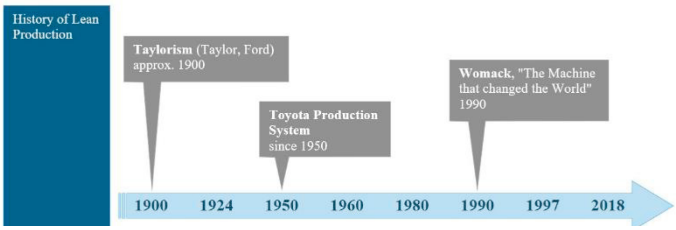


Fig. 1. Timeline of relevant milestones of Lean Production.

Experiences in the companies that have implemented Lean have shown that Lean has a comprehensive influence on a company due to positive changes in many factors, as depicted in figure 2 [16].

Fig. 2. Results obtained with Lean Production.

2.1. Brief Overview of Lean Techniques

Kaizen Assembly is unique because it focuses on the heart of the shopfloor and where the product is made: the assembly line. This approach allows for greater detail in the subject matter and gives any engineer or engineering manager the tools needed to set up a lean assembly line [17]. The Lean philosophy embraces methods and tools to support its implementation [18]. These methods and tools are meant to improve existing manufacturing systems [19]. Although lean manufacturing deeply utilizes lean tools, it is not by applying lean tools that a company will succeed to implement lean manufacturing. In the book "The Toyota Way" it is also explained that lean tools are just the tip of the iceberg of lean manufacturing [20]. Value Stream Mapping is a method of lean manufacturing which uses symbols, metrics and arrows to show and improve the flow of inventory and information required to produce a product or service which is delivered to a consumer [21]. Value stream mapping is a tool which enables a company to map the process flow that helps in identifying various factors like: value added time (time taken for producing the end product); Non-Value-added time (time taken which do not contribute to the production of end product); Cycle time (time required to perform a process) and Changeover time (time required to change tool and programming, etc.) [21].

The first step is to study, observe and provoke the current state with the current state map. Then, the future requirements of the system should be described with the future state map. The last one is to build up the action plan in detail [22]. The general process and typical VSM icons are shown in figure 3.

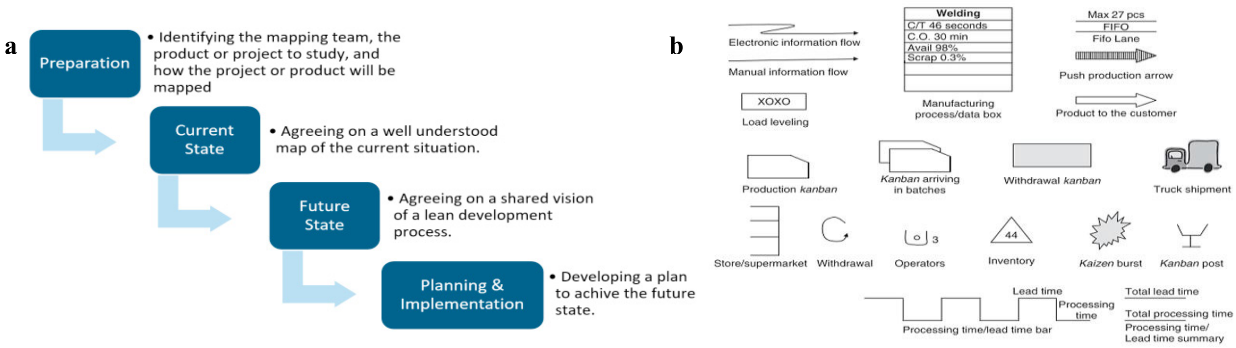


Fig. 3. a) The value stream mapping process; b) Typical value stream mapping icons [14].

Lean Line Design (LLD) is a method for implementing manufacturing industries principles like process orientation, perfect quality, standardization, flexibility, waste elimination, transparent process, associate involvement, etc. LLD technique is as shown in fig. 4. While planning the new design of manual and semi-automated work systems, this LLD technique is required to result in the better line. [23].

Assembly line balancing includes assigning tasks to a set of workstations with consideration for constraints set of precedence relationships, processing time and the cycle time [24]. One major goal of line balancing is to achieve a similar cycle time at each station [25].

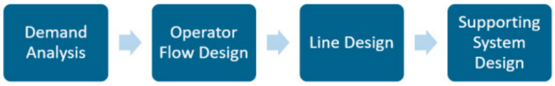


Fig. 4. LLD technique.

3. Motivation and problem statement

This study deals with a complex manual electronic devices assembly line composed of 16 workstations and 5 test tables at the end of the line to assess and measure all products in a time period of 12 hours. The product complexity requires a rigid schedule and a rigorous respect of the takt-time. For these reasons, the line balancing, the fixtures used for assembly and process sequence properly architected are a core activity and needs to be efficient and effective. The company where this study was implemented already has established a production culture based on LM philosophy, in which the organization work methodologies are focused on a lean mindset environment, and, for these reasons it was a remarkable challenge and more difficult to find production waste. However, after a thorough observation of this assembly line, some problems were detected to be analyzed, as the area occupied, the time needed for the operator to change workstations, the production capacity and the flexibility of the line to get new products. In order to overcome this drawback and to eliminate waste, a new ergonomic incorporated layout and a new approach to fixtures design needs to be developed. Change in work methodologies and redesign of the layout lead to takt-time reduction and remove non-value-added activities.

4. Methodology

Workers in the assembly line carry out a variety of tasks to produce the final products. There are many tasks in the different stages of the work process which includes tightening the components using fasteners, using mount fixtures, operating machines, testing the assembled product and build the package.

The procedure involves analyzing the process flow with the help of lean tools with the main goal of reducing waste. Essentially, it was necessary to: collect process data, as tasks and compile them; realize which are valuable and which are wasteful and determine improvements opportunities.

A process line under an intensive lean environment in which workers can be rotated through all workstations within the cell to finish the product was considered for the study. The line will have to be monitored to observe the man flow, the process sequence, the fixtures used and the ergonomic aspects. Layout details including reach of tools and parts and distance between each workstation were taken into account. This industrial study was carried out in parallel with a new industrialization project for a new model that will be integrated into the same production line. Taking this project into account, it was necessary to evaluate the assembly sequence, specify the necessary tools and workstations. In order to have an efficient industrialization of this new model, it was important to consider how it will be possible to combine tools and probably the same workstations, in order to design the layout and the appropriate assembly process that contemplates this new reality.

5. Analysis and optimization of an assembly line

5.1. Value Stream Mapping (VSM)

The VSM analysis permits identifying specific root causes bringing problems across value stream. The VSM method is only an analytical method and does not remove the manufacturing issues or root causes by itself. Therefore, it is a relevant tool to identify problems that others lean methods could fix. Due to the variety and complexity of electronic devices assembling the VSM chart illustrated in figure 5 represents the flow value stream chain of the product version with the high demand of the production line studied in this paper. The aim of this technique is mainly focusing on the final assembling line of this kind of products, taking into account the identification of improvement opportunities related to reducing takt-time outcome for a better line balancing and workspace optimization.

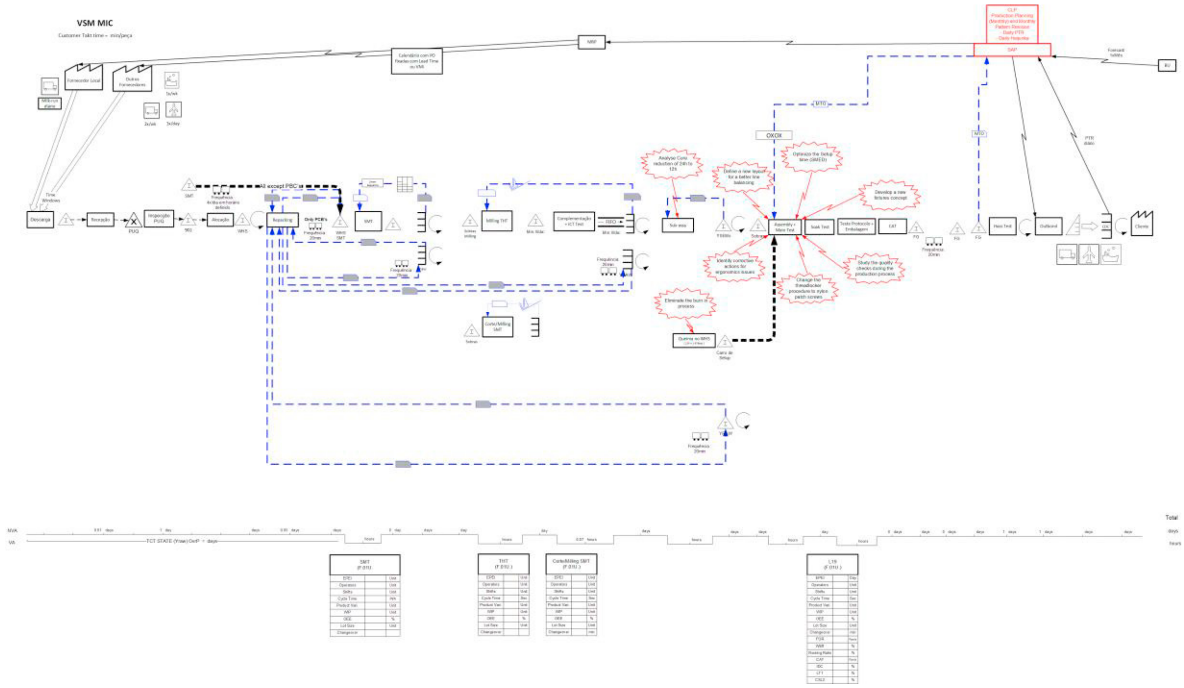


Fig. 5. Value Stream Mapping of a complex electronic devices assembly.

5.2. Lean Line Design (LLD)

In this case, the LLD method was applied to an optimization of the production line, improving the output of different product family versions. Thus, the reason for applying this tool was to eliminate some ergonomic problems that have been identified as critical, decrease target cycle time, reduce the area occupied, improve the walking flow, combine all workstations and equipment's in the same space.

The actual state was established by recording the current data and times for the line that needs to be redesigned as a Lean line in the future step. The actual state promotes a better understanding of the work steps and their interaction. Thus, in figure 5 is shown the actual state with the condition of having eight operators working in the line. The information determined in figure 5 is the current line layout, work distribution diagram unbalanced 7% and the loop time for each operator that gives a total of 185 seconds moving across stations.

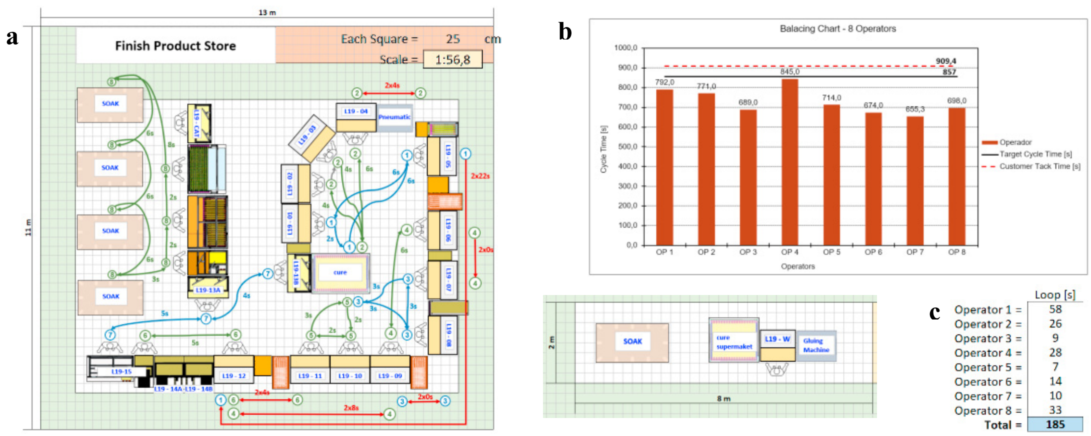


Fig. 6. a) Current line layout; b) Work distribution diagram; c) Loop time for each operator.

To get a clear understanding on how the layout redesign will be done, it is important to work in a true scale environment, to make possible an easy rearrangement of workstations, the equipment and material supply. Therefore, multiple alternative concepts of the layout were developed to select the best approach to be implemented. In Table 1 is registered the different properties taken into account to have the most exact decision about which layout option creates more improvements to the line. The evaluation of layout option concepts implies and involves both comparison and decision making. Thus, for better determination, the assess was determined by a decision matrix method.

Table 1 - Properties data collect of the different Layouts options

LAYOUT	*Area Occupied [m^2]*	*Cost of Implementation [€]*	*Capacity Required [pcs/wd]*	*Operator Flow [m]*	*Unbalancing [%]*	*Target Cycle Time [s]*
Option 1	93.8	2000	32	76.5	7	857
Option 2	93.8	3000	32	98.0	7	857
Option 3	93.8	2500	32	75.5	7	857
Option 4	**82.8**	6000	**35**	**50.5**	**2**	**784**

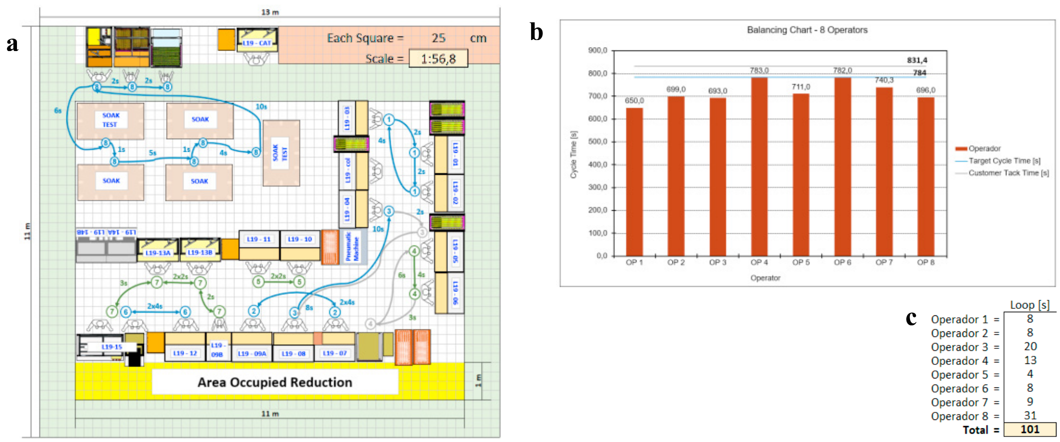


Fig. 7. a) Future line layout; b) Work distribution diagram; c) Loop time for each operator.

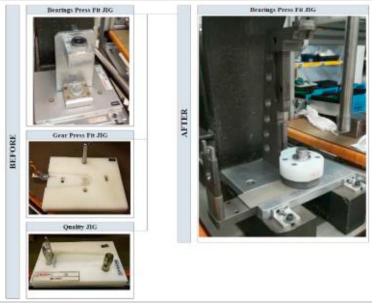
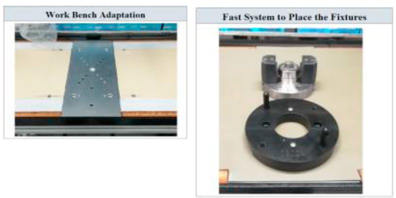
The main improvements identified are summarized by: an unbalanced workload line of 2%, which implies a decreasing in the target cycle time and corresponding the tack time, resulting in a capacity of 35 pcs/wd; short routes in changing workstations. The reduction is approximately 54.5% of walking in the operator's loop and a reduction of the area occupied relatively to the current state in about 27 m^2 that corresponds to a win area of 25%.

5.3. Production Process Optimization

In order to improve productivity and efficiency in each workstation on this complex manual assembly line, a deep knowledge of the product design is mandatory, in a way to understand where the production wastes are and how this assembly line can be optimized. After the operation process has been analysed, the operator value-added and/or non-value-added activities were identified for every workstation. At each workstation, all operations processing cycle time were collected. The following topics are summarizing some wastes reductions.

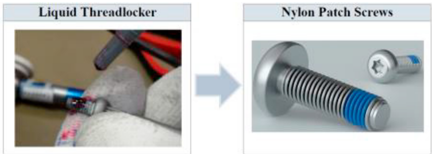
After the observation, registration and analysis of all fixtures used for assembly two models of one product in a complex manual production line, it was possible to deepen knowledge about the process and the improvement needed it to develop a new approach concept to redesign the mounting fixtures. The complexity criteria are intended to be used by engineers in manufacturing engineering for identification of potential quality issues in the development of assembly solutions. In order to overcome this drawback, the new design concept for the fixtures was based on modular fixtures systems those consist of using interlocking standardised elements such as dowel pins, clamps and connections. Flexibility is achieved through the interchangeability of different modules, which enables a modular fixture to be easily disassembled and re-assembled. The great benefits of this design are: reducing the setup time (SMED improvements); be easier to maintain, having spares to change when needed; reducing costs of new fixtures with the same configurations, only need to design some elements to new models and a better 5S implementation. In table 2 are represented some examples implemented with the mindset in the previous state.

Table 2 - Some examples of assembly fixtures improvements developed for line

Figures		Details
	**What?**	Combine 3 fixtures used in the same workstation in just one.
	Why?	These are different process steps, that are critical to assure the proper functionality of the product. Multiple fixtures changes; misalignment of the parts; a larger space to store the fixtures in the production line.
	Results	• Cycle time reduction of this station; • With the development of a single fixture, the need to use 6 fixtures for the assembly of two versions of the product was eliminated; • Reduction setup times (SMED).
	**What?**	Redesign a different method to plug in the product to leak test.
	Why?	In this operation, it was detected an ergonomics issue on tightening the cap and the time needed is too long.
	Results	An elimination of the ergonomics concerns; a reduction of the time operation approximately 25 seconds and cost saving due to eliminating the need to order the customs caps.
	**What?**	Redesign a different method to place the fixtures on the workbenches.
	Why?	In this production line, many of the workstations need the equipment to be tightened at the workstation, causing the time to perform this operation to be high.
	Results	Due to the reason of creating a different workbench system with a custom aluminium plate in the middle, the results were: elimination the need to tight fasteners for the fixtures be stable; a SMED improvement with reduction of the time operation of approximately 15 minutes in the line.

The main target of this step is to optimize the workplace regarding all manual tasks that imply quality verification or process steps. It is intended to identify unnecessary activities wish do not generate value-added to the products, as well as remove unnecessary items. In this paper, only important improvements have been highlighted in terms of relevant impact on the assembly process, such as assembly time, a number of needed assembly operations, takt-time of the assembly line and overall manufacturing costs. Thus, one of the improvements done was eliminate a quality checklist used in time for having a double process validation by operators in line. This task corresponds to sign and write down the date of the operation done in each workstation by the operator. Another improvement studied was the practice of dispensing a drop of glue with the thread locker characteristic onto all the fasteners in the product, as well the cleaning preparation to apply to this kind of adhesives. Obviously, liquid thread lockers are messy, can be forgotten and the time needed to execute this task is identified as non-value-added, so the main target is to investigate a different solution assuring the specification requisites of the product.

Table 3 - Some examples of assembly process improvements.

Figures		Details
	**What?** **Why?** **Results**	Eliminate the time needed to sign the quality checklist. In terms to detect a possible failure during the assembly process, this technique is not truly effective, due to the reason that is filled by the operator themselves. It was observed that all tasks sign in the checklist is validated by an automatic functional test. Time reduction of approximately 3 seconds for each workstation.
	**What?** **Why?** **Results**	Change the process of liquid thread locker to screws with nylon patch. Nowadays, it is possible to find catalogue solutions in the market that could substitute work made by hand. The Nylon Patch screws assure the anti-vibration solution and eliminate an overprocessing waste. Cycle time reduction for each workstation and guaranty that all screws fulfil the product specifications.

Analysing figure 9 and table 4, it is possible to see that a decrease of 289.8 seconds is verified in the duration of the entire process sequences necessary to accomplish a final product. One of the improvements actions with more impact will be changing the practice of applying thread lock glue to the screws for a solution of nylon patch screws, however, this improvement is ongoing by the development team. Nevertheless, these changes represent an improvement of 3% when compared to the results achieved through the LLD implementation, with the following results: 0% of unbalanced; a decrease of takt-time to 808.3 sec/pc comparing with 831.4 sec/pc, with a production capacity of 36 units per day.

Table 4 – Time gain with process improvemen.

Improvement Classification	Time [s]	
Fixtures Adjustments	26	9%
Assembly Operation	40	14%
Quality Checking	39	14%
Change to Nylon Patch	182.8	64%

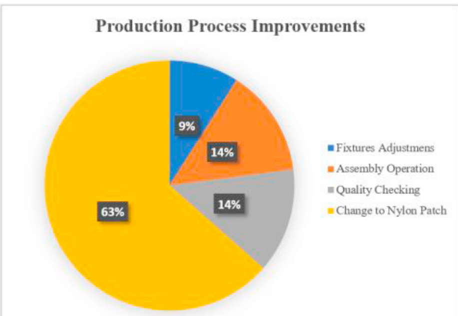


Fig. 9. – The different types of improvements.

PROCESS IMPROVEMENTS	Time per Task (seconds)	Fixtures Adjustments	Operation	Quality	Nylon Patch	COMMENTS
WORKSTATION 1						
Change the Adaptor from the manual press fit	5,0	x				A new adaptor
Process of liquid threadlocker	7,0				x	Change threadlocker loctite to screws with nylon patch.
Fazer Check list	2,0			x		Remove the task
WORKSTATION 2						
Change the Adaptor from the manual press fit	5,0	x				A new adaptor
Process of liquid threadlocker	7,0				x	Change threadlocker loctite to screws with nylon patch.
Fazer Check list	2,0			x		Remove the task
WORKSTATION 3						
Process of liquid threadlocker	10,0				x	Change threadlocker loctite to screws with nylon patch.
Fazer Check list	2,0			x		Remove the task
WORKSTATION 4						
Press the gear into the shaft	5,0		x			Critical ergonomic issue; Aquisition of Pneumatic Press
Move to a different press fit and place bearings	5,0		x			In the same press fit
Change the adaptor	5,0	x				The same adaptor for all operations
Fazer Check list	2,0			x		Remove the task
WORKSTATION 5						
Quality check of the springs placement from the previous assembly	10,0			x		Check on the functional test
Tight two heyco nuts with a wrench	10,0		x			Replacement for electric screwdrive
Process of liquid threadlocker	13,5				x	Change threadlocker loctite to screws with nylon patch.
Fazer Check list	2,0			x		Remove the task
WORKSTATION 6						
Process of liquid threadlocker	18,5				x	Change threadlocker loctite to screws with nylon patch.
Fazer Check list	2,0			x		Remove the task
WORKSTATION 7						
Place the fixture in manual press fit	3,0	x				
Change the fixture in manual press fit	3,0	x				
Tight the arms parts to the product	10,0		x			
Quality check of the gear position	5,0			x		
Fazer Check list	2,0			x		Remove the task
WORKSTATION 8+9+10+11+12						
Process of liquid threadlocker	126,8				x	Change threadlocker loctite to screws with nylon patch.
Fazer Check list	10,0			x		Remove the task
WORKSTATION 15						
Place the leakage fixture in the product	5,0		x			New tool design
Plug the air connection	5,0	x				
Take off the leakage fixture in the product	5,0		x			
Fazer Check list	2,0					Remove the task
Total =	289,80 s					

Fig. 8 - Detailed data of tasks improved.

6. Discussion and Conclusions

This study leads the development of methodologies which incorporates an initial drawing of VSM to visualize the improvements needed to be done with the help of methods, such as assembling optimizations and the technique LLD, involving line balancing layout design and walking paths, which have been simulated and verified in an assembly line. From the results, we can infer that determined improvements can increase productivity by approximately 10% with the same manpower by modifying workstations and work methodologies. The process of workstation design plays an important role, in increasing performance and quality indicators into the organizations. Taking this into account, we can conclude that when it is necessary to redesign the layout of a low volume batch production line, the best way to confront this activity is to imagine a possible re-engineering of the process with the aim of reducing waste, according to lean manufacturing principles.

The quality of the electronics assembly line was enhanced in terms of line balancing, overall labour effectiveness, productivity and elimination of wastes. This research shows that there is much wastes which could be eliminated with simple lean tools. It is not very complicated, but it would bring essential benefits. After the line is balanced, standardization of works should be done. Other lean tools such as 5S, SMED, or TPM should be studied, which could support setting up the lean environment for these complex production assembly line.

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