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Reconfiguration of assembly lines using Lean Thinking in an electronics components' manufacturer for the automotive industry

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Abstract

This article discusses the reconfiguration and improvement of electronics components assembly lines through the use of Lean Thinking principles. This reconfiguration was undertaken in a project that followed the action-research methodology. There were three main distinct problems related with the outdated assembly lines. The first came from a diagnosis of the assembly line itself, where quality problems and difficulties with compliance with the takt-time were identified, as well as activities that do not added value. The second happened due to an adjustment in demand that requires a reconfiguration of the line and, the third problem, related to the integration in an existing assembly line of a new process for a product pertaining to the same family, forcing the exploitation of synergies in production of these two products. Regarding the improvement proposals, some managed to be implemented in a timely manner, others, despite not having been implemented, their impacts has been predicted. Overall, the level of scrap was reduced by 57% through the implementation of the Lean Six Sigma methodology, and the cycle time of an operation was reduced by 12,5% by eliminating non-value adding operations. Also, gains were obtained by reducing the previous occupation with the project of an assembly line segment dedicated to the new product. With this, a reduction of one employee with the integration of two workstations was achieved.

Keywords: Automotive components, Lean Thinking, Lean Six Sigma, Reconfiguration of asssembly lines, Automotive Industry

1. Introduction

The automotive industry has been faced with an economic situation that has threatened its status from being an industry where sales were growing year after year and, therefore, it was a prosperous sector [1]. According to data revealed on the Statista website, the volume of car sales, which since 2015 had constantly increased, faced a drop in 2018 [2]. Furthermore, the pandemic crisis caused by Covid-19 has aggravated the situation, given that new forecasts point to a 20% drop in car sales for the year 2020, with the worst scenario pointing to a decline to 40 % [3].

Thus, an industry that has remained stable for decades, is now faced with new paradigms [1]. These paradigms involve car sharing, automobile electrification, the emergence of technological companies that announce new competition to cars utilization and alternative means of transportation, and the mandatory compliance with the environmental restrictions trying to reduce the environmental footprint [4,5]. These paradigms constitute a more hostile environment for the automotive industry under competition, and this environment is replicated regarding the automobile manufacturers suppliers. Therefore, the implementation of philosophies such as Lean Thinking [6] and methods that reduce production costs and improve the productivity of production systems by eliminating wastes becomes an indispensable requirement [7,8-10]. For instance, the assembly lines that, in times, were designed to high volumes and low variety are currently frequently reconfigured to attend the market variable trend what is not always an easy decision to make [8,10,11].

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It is in this context that this project was undertaken. It was developed in an electronic components automotive supplier company where it is mandatory to always reduce the wastes by frequent reconfiguration of the assembly lines [12,13,14,15,16]. This article presents the reconfiguration and improvement of assembly lines for a specific product in this company. Also, it was studied the introduction of a new product in an existing assembly line by reconfiguring it or design a new assembly line.

This article is structured in six sections. The first section sets out the project and its objectives. Then, the second section addresses the research methodology used in the development of the project. Section three presents a brief review of the literature, referring to important concepts about Lean Thinking and some tools used. The description, analysis and presentation of proposals for the improvement of the assembly lines are presented in section four. Section 5 presents the discussion, the evaluation of the results obtained, and expected with the implementation of the proposals. Finally, the conclusions are drawn in the sixth section.

2. Research methodology

The methodology used in this work was Action-Research, which is characterized by the involvement of the researcher in the environment where the work will be developed, drawing knowledge from it and applying others combining empirical and practical knowledge [17,18]. According to these authors [17,18], this methodology consists of five cyclical phases: 1) Diagnosis; 2) Action planning; 3) Implementation of actions; 4) Evaluation; 5) Learning specification.

The first is the phase where the faced problem is defined and the critical situations whose are compromising the productive system are identified. The action planning phase means that solutions are designed, responding to previously identified problems. After this phase, the stage of implementing them is performed, followed by the phase of evaluation of the results. In this specific case, some performance indicators are used to allow an evolutionary comparison to be made and, thus, to understand whether the objectives were achieved or not. Finally, it was performed a reflection on what has been achieved and what links can be drawn for the future of the iteration performed.

3. Brief literature review

Lean Thinking had its genesis in 1945, when Japan lost the war and at that time, the Toyota's president warned that for the survival of the Japanese automotive industry, it would be necessary to achieve the American productivity ratio in three years, because the workers ratio was one American to nine Japanese workers. To this end, the Toyota Production System (TPS) was developed, and was created by Taichi Ohno, who sought to achieve this goal by minimizing waste as much as possible. According to Ohno [19], there are seven wastes: overproduction, waiting, transport, overprocessing, inventory, unnecessary movements and defective products.

In 1988, Krafcik [20], a researcher from MIT, introduced the term Lean Production System in a comparative study that he did between the Japanese and the American automobile production system. However, it was only in 1990 that Womack, Jones, and Roos [21] popularized the concept of Lean production in their famous book *The Machine that Changed the World* by presenting a western version of TPS, also making a parallel between Japanese and American performance of the productive systems, having concluded that the former was undeniably superior to the latter. In 1996, this production concept was expanded from Lean Production to Lean Thinking with Womack and Jones [6], in order to reinforce the need to implement Lean as a way of being, transversal in the organization as a whole. It thus presents five elementary principles: 1) Value - as something that is defined and determined by the customer; 2) Value chain - as a set of actions that must be performed to complete the product; 3) Flow - where this productive flow must be continuous; 4) Pull production - where it is pulled by the customer and not pushed by the producer; 5) Search for perfection - referring to the continuous elimination of waste, also called continuous improvement.

One way to follow and achieve the principles mentioned above is to use a set of tools such as process mapping, standard work, balancing and leveling, for example [22].

For the case of needing a methodology focused on solving problems that require a framework designed to address problems associated with quality, but not only, Lean Six Sigma can be considered. This tool is based on a logical structure of five steps that must be followed sequentially: Define, Measure, Analyze, Improve and Control (DMAIC) [23-25]. "Define" corresponds to the problem definition and where the spectrum of the project [23] is clarified. In the "Measure" phase, it is intended to find out about the current state of the process where the problem occurs, and to collect reliable information (data) to guide the search for the root cause of the problem [23]. In the next step ("Analyze"), the collected data is analyzed, and the root causes are determined and then implemented in the "Improve" phase. Their improvements implementation effects are further controlled in the "Control" phase.

Prior to the use of the described tools, the suitability of the installed production system must be investigated and, if necessary, reconfigured, to ensure that the product is produced in a suitable system, without waste [26]. Although changing the system can sometimes be a difficult decision to make, failing to do so may entail more costs than the strictly necessary [26,27]. For this reconfiguration, design methodologies and/or reconfiguration of production systems can be used, namely, the methodology of Monden [28], Black and Hunter [29] and Alves [30]. In the present work, the last one was the selected methodology. This methodology is divided into three project phases: generic, conceptual and detailed planning, the latter being the most important for the project shown in this article. The detailed project includes five phases: 1) Formation of Product Families; 2) Instantiation of Conceptual Cells; 3) Instantiation of Workstations; 4) Intracellular Organization and Control of Each Cell; and, finally, 5) Integrated system Arrangement [27,30-32]. In step 1), product families are formed, whenever justified by the variety of products and their mixture [27]. In step 2), it is intended to determine the most appropriate operational configuration for the cells. In step 3), it is intended to find the jobs to be used, as well as the number and type of skills of the employees to be integrated. In Step 4), the cell is organized in order to find a suitable arrangement for the machines and equipment, defining how the operators will organize themselves. In the last phase, it is proceeded to the integrated arrangement of the Product-Oriented Production System, defining the intercellular implantation of cells / lines, and, therefore, how they will be disposed and related to each other [27,30-32].

4. Description, analysis, and proposals presentation

This project was developed in a multinational firm that produces electronic components for the automotive industry. The assembly line in focus is one dedicated to produce an electronic module. This section presents the description of such line as well as the problems and solutions to solve the problems.

4.1. Description of the assembly line and production process

The production process of the electronic module consists of two boards: a power system board and an electronic board which have different processes up to a certain point, in which they are joined and will undergo the same processes. Fig. 1 illustrates the different paths that the boards go through (red and blue routes) and the route when they go together in final modules (green route).

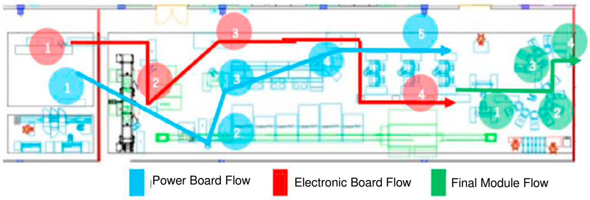


Fig. 1. Boards productive flow.

Starting the route with the red point 1., as can be seen from Figure 1, the electronic board came assembled from another building in the factory. The first process that the electronic board undergoes is the cleaning process represented by point 1 in red, where the boards are subjected to a suction process in a “tornado” that removes impurities from the boards, ensuring that they are free of debris before proceeding to the next process. This process (number 2, red) is the Coating, where the plates are covered with a kind of varnish that protects the electronic components from moisture. Then, they go to point three, in red, where they wait 30 minutes until the Coating layer consolidates. The last process of these boards is the Press-Fit where they match the power board. This board starts its process at point 1 in blue. At this point, the boards are engraved with their code on a laser machine. Then, they go to point two, blue, where, in the THT (Through Hole Technology), diodes and connectors are inserted. Then, some properties are tested in the ICT (In Circuit Test) (point 3, blue) before going to the Fuse Insertion (point 4, blue). Here, the fuses of the power boards are inserted. Finally, the power boards go to the Press-Fit, which consists of three pairs of Press-Fit, where in the first of each pair other connectors are inserted and in the other the junction of this board is made with the electronic one. After the Press-Fit is completed, the set of boards go to the H&L (Housing & Labelling), represented in green by point 1. At this point, the lower cover is placed, labeled, and the upper cover is placed. After completing these operations, the module is physically constituted. The next step is to carry out a functional test to the module, which is done in point 2, in green, in the FTs (Functional Test). After the FT, the modules go to the RF (Radio Frequency) test (point 3, green), where the software is installed, and a test is performed simultaneously. Finally, the modules go to the packaging, where they are placed in the packaging for the customer (point 4, green).

4.2. Identification of problems and critical analysis

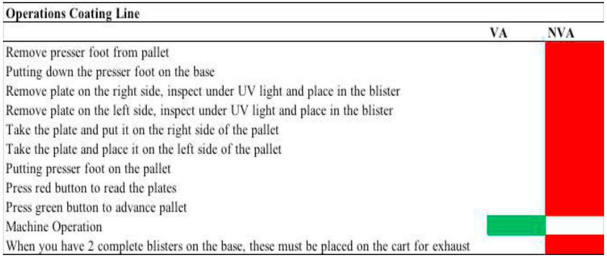
In this section, the identified problems are presented. For that analysis, a Time Study was carried out, identifying the critical stations. In this analysis, three workstations have been signaled: ICT, FT and Coating, being ICT the most critical as its cycle time was higher than the takt-time. However, the problem was due to technical issues, whose were rapidly solved in the meantime. A Pareto’s analysis of the defects and a non-value adding analysis were also carried out.

4.2.1. Lack of capacity in FT

Once the difficulty in complying with the 13-second takt-time was identified, since it had a cycle time of just over 13 seconds (13.04 seconds), it was analyzed, using the machine number formula, where the machine processing time is divided by takt-time, and it was obtained for both the module with the highest processing time (98.8 seconds) and the average processing time (91.28 seconds). The result was in both cases greater than seven pieces of equipment (current number).

4.2.2. Non-value adding operations in Coating Line

Since this was the third station with the longest cycle time, it was tried to observe it, assessing the sequence of operations and determining the possibility of eliminating some of these activities, considered as wasteful. Analyzing the Fig. 2, it seems that only one operation is considered of added-value (VA; green color), all others being waste (NVA; red color).



Operations Coating Line	VA	NVA
Remove presser foot from pallet		🟥
Putting down the presser foot on the base		🟥
Remove plate on the right side, inspect under UV light and place in the blister		🟥
Remove plate on the left side, inspect under UV light and place in the blister		🟥
Take the plate and put it on the right side of the pallet		🟥
Take the plate and place it on the left side of the pallet		🟥
Putting presser foot on the pallet		🟥
Press red button to read the plates		🟥
Press green button to advance pallet		🟥
Machine Operation	🟩	
When you have 2 complete blisters on the base, these must be placed on the cart for exhaust		🟥

Fig. 2. Added and non-value adding operations in Coating Line.

Thus, the operation of the workstation was observed, and it was noted that the activity of removing the presser foot from the pallet and placing it on a base to then put it back on the pallet, with the new boards ready to go back to the machine, could be eliminated.

4.2.3. Adjusting the equipment number

As demand dropped, the takt-time that was previously 13 seconds rose to 14 seconds (30 000 units per week to 28 000 units per week). Thus, it became essential to understand whether it was possible to readjust the amount of equipment in order to reduce the excess of installed capacity. For this reason, a capacity graph was elaborated (Fig. 3).

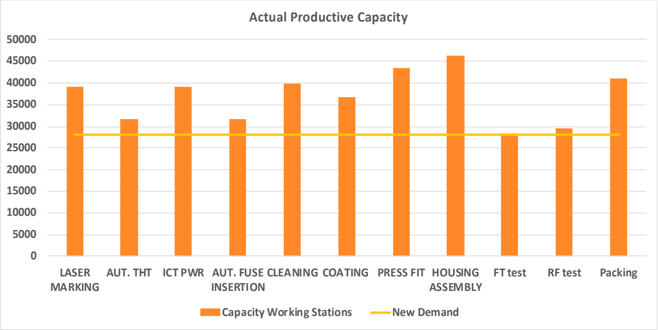


Fig. 3. Current productive capacity.

From this graph (*Fig. 3*), it seems that there are many stations with excessive capacity. However, only three can be reduced: Coating, when removing a module from the Coating Stand Alone, Press-Fit when removing a pair and Housing Assembly (H&L), when removing one of the workstations. It was then simulated to withdraw from these workstations and the graph of Fig. 4 was obtained.

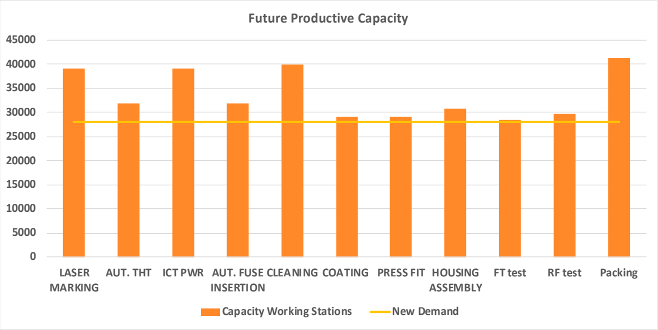
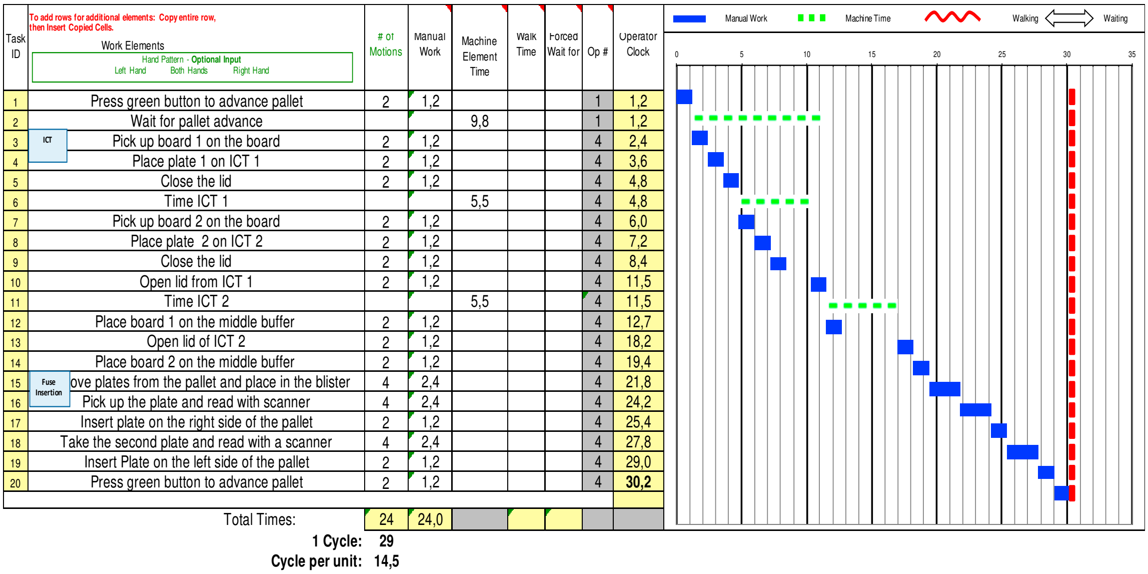


Fig. 4. Future Productive Capacity.

From the graph in Figure 4, it is possible to see that the necessary capacity is not compromised, at the same time the excessive capacity is reduced at workstations where this is possible.

4.2.4. Need to integrate two working stations

Following the reduction in demand, the possibility of integrating two operations was evaluated, since by observing the ICT and Fuse Insertion, these appeared to have break times that envisage the possibility of intercalating activities in a way for a collaborator be able to operate both workstations simultaneously. It was observed that the average effective working time of the employee responsible for the ICT is 5 seconds, with 4.9 seconds dead time. In addition, the effective time of the Fuse Insertion is 9.8 seconds and the same time for the dead time at this workstation. This means that an ICT cycle fits into one of the Fuse Insertion's dead time cycles, only exceeded by one tenth of a second. This situation led to a more in-depth study by simulating through a Work Combination Table the junction of these two workstations operated by only one person. The result can be seen in Fig. 5.



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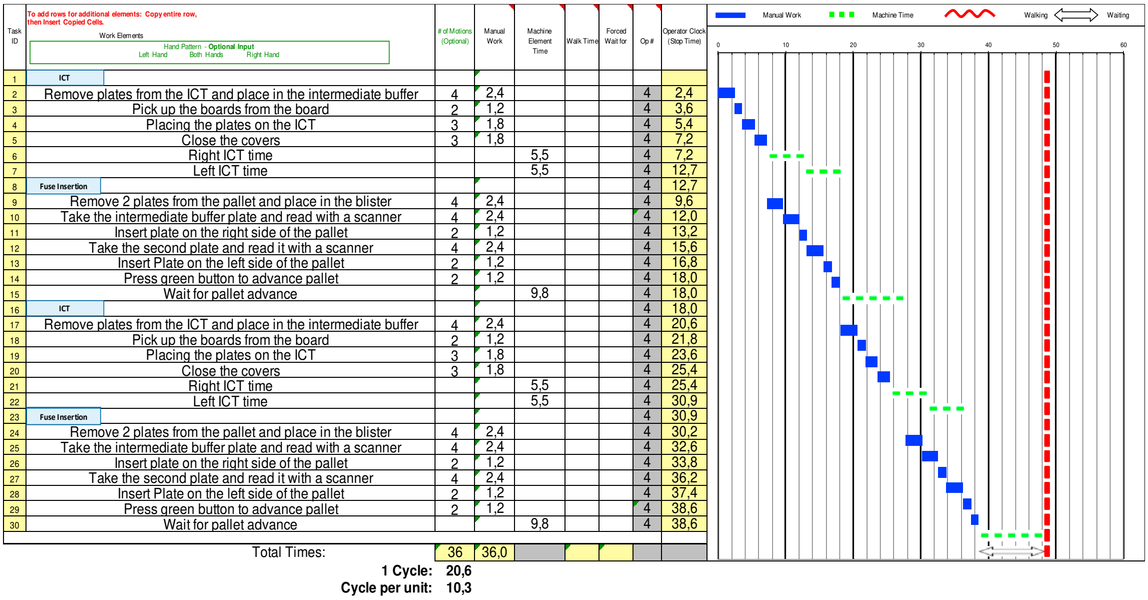
Hand Pattern - Optional Input
Left Hand Both Hands Right Hand

Task ID	Work Elements	# of Motions	Manual Work	Machine Element Time	Walk Time	Forced Wait for	Op #	Operator Clock
1	Press green button to advance pallet	2	1,2				1	1,2
2	Wait for pallet advance			9,8			1	1,2
3	ICT Pick up board 1 on the board	2	1,2				4	2,4
4	Place plate 1 on ICT 1	2	1,2				4	3,6
5	Close the lid	2	1,2				4	4,8
6	Time ICT 1			5,5			4	4,8
7	Pick up board 2 on the board	2	1,2				4	6,0
8	Place plate 2 on ICT 2	2	1,2				4	7,2
9	Close the lid	2	1,2				4	8,4
10	Open lid from ICT 1	2	1,2				4	11,5
11	Time ICT 2			5,5			4	11,5
12	Place board 1 on the middle buffer	2	1,2				4	12,7
13	Open lid of ICT 2	2	1,2				4	18,2
14	Place board 2 on the middle buffer	2	1,2				4	19,4
15	Fuse Insertion ove plates from the pallet and place in the blister	4	2,4				4	21,8
16	Pick up the plate and read with scanner	4	2,4				4	24,2
17	Insert plate on the right side of the pallet	2	1,2				4	25,4
18	Take the second plate and read with a scanner	4	2,4				4	27,8
19	Insert Plate on the left side of the pallet	2	1,2				4	29,0
20	Press green button to advance pallet	2	1,2				4	**30,2**
	Total Times:	24	24,0					

1 Cycle: 29
Cycle per unit: 14,5

Fig. 5. Work Combination Table for current functioning integration.

Figure 5 shows that with the current operation of the two workstations operated by the same operator, it would take an overall cycle time of 14.5 seconds, exceeding the new takt-time of 14 seconds. Thus, it was tried to understand how this problem could be overcome. It was found that this workstation consists of two plate test boards, only one starts to work when the other has finished the test and its lid is opened, requiring the mechanical action of the operator for the other to start the test. It was simulated in the event that the test started automatically as soon as the other board finished by inserting a solenoid that would open the plate as soon as it finished, allowing the other closed plate to start the test. The feasibility of this solution was technically validated by the manufacturer and it was necessary to simulate this new way of operating in terms of cycle time. In this sense, a new Work Combination Table was created to represent this new way of operating. The result is shown in Fig. 6.



To add rows for additional elements: Copy entire row, then Insert Copied Cells.

Hand Pattern - Optional Input
Left Hand Both Hands Right Hand

Task ID	Work Elements	# of Motions (Optional)	Manual Work	Machine Element Time	Walk Time	Forced Wait for	Op #	Operator Clock (Stop Time)
1	ICT							
2	Remove plates from the ICT and place in the intermediate buffer	4	2,4				4	2,4
3	Pick up the boards from the board	2	1,2				4	3,6
4	Placing the plates on the ICT	3	1,8				4	5,4
5	Close the covers	3	1,8				4	7,2
6	Right ICT time			5,5			4	7,2
7	Left ICT time			5,5			4	12,7
8	Fuse Insertion						4	12,7
9	Remove 2 plates from the pallet and place in the blister	4	2,4				4	9,6
10	Take the intermediate buffer plate and read with a scanner	4	2,4				4	12,0
11	Insert plate on the right side of the pallet	2	1,2				4	13,2
12	Take the second plate and read it with a scanner	4	2,4				4	15,6
13	Insert Plate on the left side of the pallet	2	1,2				4	16,8
14	Press green button to advance pallet	2	1,2				4	18,0
15	Wait for pallet advance			9,8			4	18,0
16	ICT						4	18,0
17	Remove plates from the ICT and place in the intermediate buffer	4	2,4				4	20,6
18	Pick up the boards from the board	2	1,2				4	21,8
19	Placing the plates on the ICT	3	1,8				4	23,6
20	Close the covers	3	1,8				4	25,4
21	Right ICT time			5,5			4	25,4
22	Left ICT time			5,5			4	30,9
23	Fuse Insertion						4	30,9
24	Remove 2 plates from the pallet and place in the blister	4	2,4				4	30,2
25	Take the intermediate buffer plate and read with a scanner	4	2,4				4	32,6
26	Insert plate on the right side of the pallet	2	1,2				4	33,8
27	Take the second plate and read it with a scanner	4	2,4				4	36,2
28	Insert Plate on the left side of the pallet	2	1,2				4	37,4
29	Press green button to advance pallet	2	1,2				4	38,6
30	Wait for pallet advance			9,8			4	38,6
	Total Times:	36	36,0					

1 Cycle: 20,6
Cycle per unit: 10,3

Fig. 6. Work Combination Table for future functioning integration.

In this situation, the cycle time would drop to 10.3 seconds, making this solution feasible (lower than the takt-time).

4.2.5. High Volume of Scrap in Press-Fit

Regarding the press-fit waste volume, it was found that it represented about 23% of the total waste of the different processes of the product line "A", being the second highest value. The first concerns were about the coating process, but it was already solved through an independent project. In this way, it was intended to form a team that would implement a Lean

Six Sigma project using the DMAIC framework as a way to solve the identified problem.

Starting with the Define phase, it was established that the scope of the work would be focused on three pairs of existing Press-Fit, and that the starting point of which would be in January of 2020 with 1172 ppm of scrap and the objective would be to reduce 30% of this volume, to a level of 821 ppm (Fig. 7).

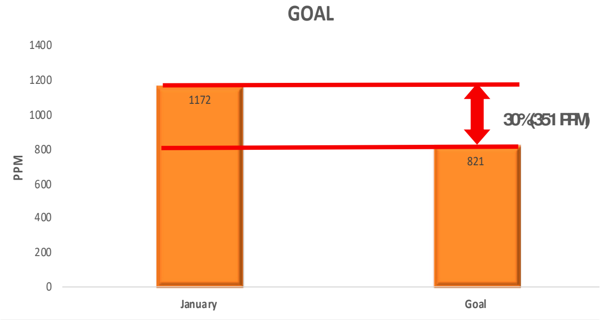


Fig. 7. Goal chart for the defects.

Moving on to the Measure phase, the defects began to be measured and it was concluded that the defects in question were of two types: the first, which is the most representative of them and consists of the appearance of damage on the perforations of the boards in a localized manner, designated type B; the second, less representative, is associated to damage which extends through all or a large part of the series of the boards' perforations, type A damage. In Fig. 8 it is possible to observe that the least representative damage is type A, with 17.5% of occurrences, against 82.50% of occurrences for type B defect.

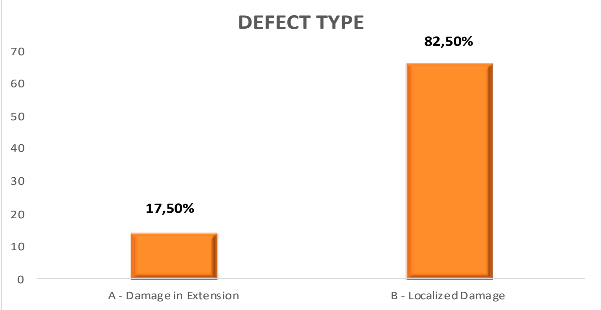


Fig. 8. The two types of defects: A and B.

In addition, an analysis was made for the two types of damage in which, in addition to locating them along the board, the areas of greatest concentration were checked if there was any relationship between the Press-Fits. Regarding the type B defect, this relationship was not found, since the damage distribution was similar between the three pairs of press-fits. For this reason, it was sought to know the distribution of the defect by shifts, with no evidence of disparity, also. However, for damage A, it was found that there were more occurrences in one press-fit than in others. This became subject of further analysis.

Thus, moving to the analysis stage, a fishbone diagram was elaborated with the objective of deepening the analysis and finding different possibilities for the occurrence of type B defect (Fig. 9).

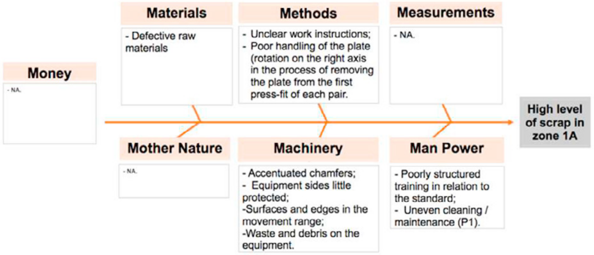


Fig. 9. Fishbone Diagram for type B defect.

Thus, possibilities were found for the field of materials, methods, machine and labour. Out of a total of nine hypotheses, three were excluded due to lack of evidence, considering as possible causes (a) the fact that the work instruction is unclear, (b) the possibility of rotating to the right when removing the board of Press-Fit, (c) the existence of accentuated chamfers in the equipment drawer where the board is inserted, (d) the sides, surfaces, and edges within the reach of the movement are also poorly protected and, finally, (e) a poorly structured formation in relation to the standard work. After the validation of these possible causes, the respective corrective actions were formulated.

For type A defect, a fault tree was created, as in this case the previous measurement of the problem had identified that the root cause could be more related to the process and product than the other factors considered in the fishbone diagram (Fig. 10).

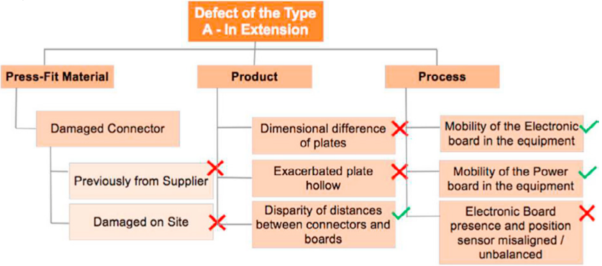


Fig. 10. Failure tree analysis related to type A defect.

In this tree (Figure 10), problems were considered in the scope of the raw material, the product and the process, having been verified within the product category, as a disparity of distances between the connectors and the board was observed. Also, in the process category, mobility of the two plates in the equipment was observed, which should not occur.

From these validated situations, the analysis was deepened using 5Whys tool, concluding that there was a problem in the pressing mechanism. This problem pressed with a slight gap, hence the disparity in distances between connectors, and the mobility of the boards can be explained by the differences in diameter of the guide pins of the equipment. Corrective actions were then outlined.

The next step was to discuss corrective actions outlined, being prioritized according to the ratio between execution effort and expected benefit. In this way, an effort-benefit matrix was created, which result was materialized through a scheduled and prioritized action plan. The corrective actions designed included: (i) the replacement of the ball cage, that caused the unevenness of the plate; (ii) the replacement of the guide pins;

(iii) the placement of an intermediate base between the two workstations with a slight height, which would counter the rotation of the board under the right axis; and (iv) the placement of a metal base in the Press-Fit drawer that protects the pins from sharp edges and chamfers.

4.3. Presentation of proposals

This section presents the resume of the general proposals as a consequence of the previous analysis. In addition, it addresses the new assembly line and its integration, due to a new product.

4.3.1. General proposals

This section presents some proposed solutions to the problems identified in the section above.

Table 1. Table of proposed solutions.

Section: Problem	**Solution Proposal**
4.2.1: Lack of capacity	Add one more FT machine
4.2.2: Non-Value adding operations in Coating Line	New standard work by operating with one less presser foot demanding the transference of the presser from the previous finished pallet to the new one after being recharged with new boards.
4.2.3 & 4.2.4 : Excess of Capacity as demand decreases	Removal of one Coating Stand Alone, one Press-Fit and one Housing Assembly.
	Integration of two workstations by introducing a solenoid which allows ICT to work after one plate is finished automatically with lower global cycle time.
4.2.5: High volume of Scrap in Press-Fit	Replacement of the ball cage that caused the unevenness of the plate, the replacement of the guide pins, the placement of an intermediate base between the two workstations with a slight height, which would counter the rotation of the plate under the right axis and also the placement of a metal base in the Press-Fit drawer that protects the pins from sharp edges and chamfers.

Due to the space limitations, it is not possible to detail more such proposals. The focus in this paper is the introduction of a new product that forced to a decision-making: design a new assembly line or reconfiguring one of the existents. To make the decision it was followed the already presented methodologiy where opportunities of reconfiguration and integration were assessed.

4.3.2. New product: new assembly line and integration with the current one

In this section, the process of designing the new assembly line is described. This design followed the stages of the methodology of Alves [31] mentioned in the section 2.

4.3.2.1. Family product formation

The first step in the development of this new assembly line was to understand the product in order to realize whether or not it can be part of a product family. In this case, some similarities with the existing product were present as they share common characteristics. The new product was designated as product "B" and the old as product "A". Both are made up of two boards, one power and one electronic, whose are matched, and lower and upper covers are assembled. It was also determined the takt-time (TT) of this product. Attending to its demand of 500 units per week, the TT value was determined as 14 minutes.

4.3.2.2. Cell Instantiation

The next step is to instantiate cells where it is important to define well the process and assess the needs of the cell and the workstations sharing possibilities. In this case, the process is similar to that of product “A”, however with some differences, as can be seen in Fig. 11.

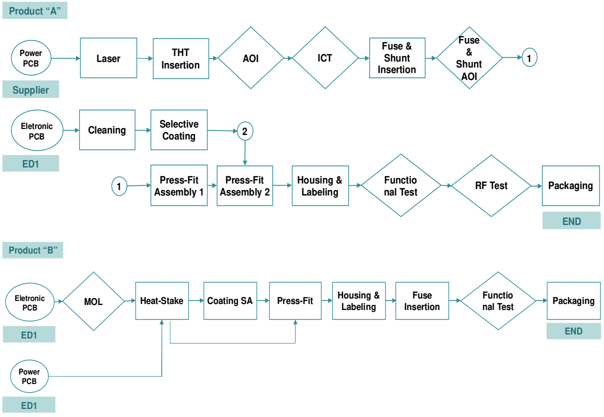
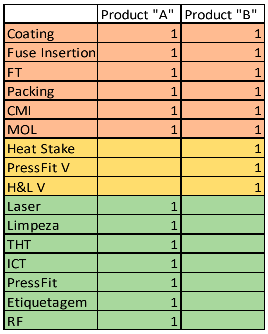


Fig. 11. Process structure between the two products (A and B).

These differences are the need for electronic boards to undergo a MOL (Middle of Line) test, similar to the ICT test, and the need for both boards to pass the Heat-Stake. Otherwise, the process is identical to that of product “A” with the exception of the RF test, which is not carried out. As the takt-time is very high and the processing times for each of the necessary equipment is much shorter, only one equipment is needed. This was followed by the assessment of equipment sharing and grouping possibilities in order to confirm it and this was done using the Direct Cluster Analysis method [33], which result is shown in Fig. 12.



	Product "A"	Product "B"
Coating	1	1
Fuse Insertion	1	1
FT	1	1
Packing	1	1
CMI	1	1
MOL	1	1
Heat Stake		1
PressFit V		1
H&L V		1
Laser	1	
Limpeza	1	
THT	1	
ICT	1	
PressFit	1	
Etiquetagem	1	
RF	1	

Fig. 12. DCA method result for products “A” and “B”.

From Fig. 12, it can be seen that the method has organized the equipment into three distinct groups, according to the needs of the two products and equipment sharing capacity. According to this interpretation, the equipment shared by both products should be grouped and the rest should be grouped by product. Therefore, it was possible to verify that it was necessary to analyze the productive capacity of MOL, Coating SA, Fuse Insertion, Functional Test and Packaging (Packing), as a way of verifying the feasibility of sharing equipment. From this analysis, only the FT was disabled, but it was previously proposed to purchase additional equipment in addition to the existing number.

4.3.2.3. Instantiation of workstations

Here the goal was to determine the number of workers needed to work with the three dedicated workstations. Once determined that number, they could be allocated through workstations. In this case, the sum of processing times of the three dedicated workstations (Heat-Stake = 22 s, Press-Fit = 22,3 s and Housing Assembly = 22 s) divided by the takt-time (831 s) determined that one worker is enough to operate them. The rest of workstations, as they will be shared, they will be operated by the existing workers.

4.3.2.4. Intracellular organization and control

The first step for this activity is to determine the space needed for this dedicated area, taking into account that it will need to have one more MOL that will be transferred from building 2 (and is shared with product "A"). Regarding that 5 MOLs need a total of 10,5 m^2, the Heat-Stake need 0,95 m^2, the Press-Fit holds for 0,8 m^2, and H&L 2,58 m^2, this gives a total area of around 15 m^2.

The following steps determined that the best local to accommodate these equipment's was the area where the Laser machine and Cleaning machine were already installed. This area was also occupied with old machines that were not in use. Thus, the next step was to determine a layout for all this equipment. It was used a Muther Diagram and a relation diagram [34]. After some intermediate proposals and taking into account the previous adjustment made to include the product "A" in the line, and the criteria of putting together the laser machine with THT machine, the final layout proposal is represented in Figure 13.

Fig. 13. Final layout proposal for the product "A" line

As there will be only one operator for the three product "B" dedicated machines, the best operating mode is one called Chaku-Chaku [35], where the operator only sticks with one part at a time, and only worries in load and unload the product through machines. It was also prepared the standard work sheets and calculated the production buffers for when producing both products in shared equipment on the product "A" line.

4.3.2.5. Intercellular and total system arrangement

The last activity consisted in organizing the new assembly line in an existent arrangement. This means that all previous connections and supply routes were reestablished.

5. Results analysis and discussion

In terms of results, the addition of an additional FT (proposal related to problem described in section 4.2.1) would result in an increase in capacity of about 4059 modules and a decrease of 1.62 seconds in the cycle time to the workstation. By reformulating the operation of the Coating Line (related to problem described in section 4.2.2), an improvement of 2 seconds was achieved in the cycle time, increasing the capacity of this Coating in more than 2241 boards.

In relation to the rejected parts (problem described in section 4.2.5), the objective of reducing the number of rejects by 30% was exceeded, as it was reduced by 57%, allowing savings in rejects of 1813 monetary unit (m.u. – unit used due to confidentiality issues) (control phase). By reconfiguring the number of equipment due to the new demand, a reduction of the occupied space is expected of about 8%, allowing a saving in occupied space costs of 1900 m.u.

The integration of the ICT workstation with Fuse Insertion will allow the saving of one employee and, consequently, an annual saving of 45000 m.u., considering three work shifts per day.

The dedicated segment of the new assembly line for the new product immediately allowed the old space to be reoccupied in another way, providing an additional space of 8.8 m^2, meaning savings of 880 m.u. per year calculated on a standard basis.

6. Conclusions

This work was part of the continuous improvement of a multinational company that is dedicated to the production of electronic components for automobiles. The main focus of the work was to improve performance by reconfiguring a main assembly line using Lean Thinking principles, among other improvements to the existing assembly lines. This reconfiguration took place according to a first phase of diagnosis on the current state of the production system. This implied an adjustment to an existing assembly line due to a change in demand by the customer, and the decision to design an assembly line to produce a new product of the same family or reconfigure the existing line in order to share resources. Overall, this reconfiguration resulted in very positive gains for the company, namely, an increase in available space by 8%, a reduction in waste by 57% and an increase in capacity in two jobs. It will also allow for future gains with the saving of one worker in the line (x3 shifts) allowing a gain of 45000 m.u. annually. These results achieved and predicted, demonstrate the utility and relevance in the application of Lean Thinking concepts in production, but also the importance of establishing preventive maintenance programs. These were, in fact, the main key leaning points. As future work, the authors advise the implementation of the proposals not yet implemented due to some constraints, as well as the continuous improvement of the production systems.

CRediT author statement

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