Pull System implementation through FIFO lane to achieve synchronism between lines and assembly cells

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Abstract

This paper presents a Lean project developed in an electronics components assembly company throughout an Industrial Management and Engineering (IME) master thesis. Since a few years ago that the company involved is in a Lean journey, implementing Lean projects in a gradual process through all the company. In this case, the Lean project was the implementation of a Pull system using a FIFO lane between a PCB assembly line and the heat boilers controllers' final assembly cells. For that, it was necessary to solve problems about lack of synchronism between different systems, visual management and high changeover time through Lean production tools. The main results obtained were not schedule changes reduction (20%) in a bottleneck workstation. Consequently, there was a deviation decrease and the stability of the cycle time. This reflected on decrease of 40% of the standard deviation in relation of cycle time. After FIFO lane application was obtained 60% return of space and reduction of the work in process.

Keywords: Lean Production, Pull System, Synchronism

1. Introduction

Nowadays, with economical crisis, the companies must reduce their costs to continue competitive. Eliminate the activities that do not add value, produce only what the costumer want and more efficient processes could be the solution to reduce costs. However, it continues being necessary to answer requirements of costumers: quality of products, delivery time and competitive prices.

These concepts are integrated in Lean Production model (Womack et al., 1990). This production model has many benefits and principles (Womack & Jones, 1996) and many companies has been adopting them. This model of production had his roots in the Toyota company that developed the Toyota Production System (Monden, 1998).

The company where this project was developed is adopting Lean principles and tools, since a few years ago. Some projects already implemented were the SMED tool (Costa et al., 2008), the reconfiguration of the assembly lines in assembly cells (Cardoso et al., 2008; Oliveira & Alves, 2009), the Pull system and kanban tool (Afonso and Alves, 2009) in others sections of the company and so on.

The project objective described in this paper was the implementation of the Pull system with an approach of a FIFO lane (Rother & Shook, 1999) between printed circuit boards (PCB) assembly lines and the heat boilers controllers' final assembly cells. With pull system, the company intended to solve problems related with the lack of synchronism between the assembly lines and the final assembly cells that assembles the boiler controllers. This lack of synchronism provoked cells stopping because of the lack of boards or overproduction near the cells because of too stock (Work in Process - WIP) accumulated between two processes. These problems happens when the output of a cell becomes the input of another, so, it is essential create synchronism and supply continuous flow of boards to avoid these problems. In addition, it's important to have efficient processes, without wastes and quicker response to customer requirements.

The methodology used to develop the project was the action research (Susman, 1983; Gilmore et al., 1986), where the researcher was involved in the real life of the company, participating and interacting in the processes. This methodology involves a five step cyclical process: diagnosing, action planning, taking action, evaluating and specifying learning.

2. Pull System in Lean Production

Lean Production (LP) was the production model adopted by the Toyota Company to go beyond the mass production paradigm implemented by Henry Ford. After the Second Great World War, Toyota company recognized its incapacity, by one side, in pursuit the mass production because of the lack of resources and, by other side, the unneeded of a system like the Ford system because of their market demand dimension. In this context, Lean means waste elimination that exists in any company, this mean consequently reducing costs too. "Doing more with less" is the key idea of LP and means fewer resources, less space, less stock, less variation and keeps customer satisfaction. So, this suggest the right part, in the right quantity, at the right time.

Waste elimination can be done through specific Lean tools and the companys can win competitive advantage because they can produce more with fewer resources and have more reliable time delivery (Paez et al., 2004; Amir et al., 2010). This involves continuous improvement, waste elimination, production oriented to customer satisfaction, mistakes prevention practices (Poka-Yoke) and pull system (Liker, 2004) among others. The success of this model have mainly based in methods and tools that was developed by Toyota sustaining on Just-In-Time (JIT) and Jidoka pillars (Figure 1) (Womack et al., 1990; Liker, 2004).

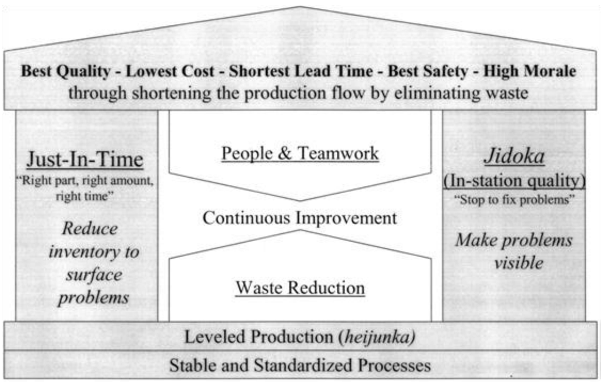


Figure 1 – TPS house (Liker & Morgan, 2006)

The JIT pillar most important concept is, mainly, the Pull system. This system assumes that each process inside the company is a customer, therefore it should receive parts (material, final product, assembly parts and others) in the right quantity and at required time (Liker, 2004). This system allows reducing stocks of final product and WIP because it only produces the quantity required. Production is pulled from the customer and production orders are released into the production when the customer wants. The coordination of production and internal logistics between different processes is very important with pull system to prevent the break or over parts/components (Monden, 1998).

One of more known pull system mechanism is the Toyota Kanban System (TKS). TKS is a replacing consumption mechanism that uses a signal, commonly a card. When material is consumed from a supermarket by an upstream process, the downstream process can start production of the same product that was consumed. Order of production is given by kanban that is send to the downstream process. There is a rule to calculate the number of kanbans in the system that is the maximum of material allowed in the system (Fernandes & Silva, 2006; Liker & Morgan, 2006).

Another mechanism that supports a Pull system is the CONstant WIP (CONWIP). This mechanism allows a mix of products, in contrast with TKS, limiting a quantity of each product. This mechanism controls WIP because when it achieves an established limit, the next order of production can only be realised when the present work finished. In addition, it limits workload of the system, i.e., the jobs only can be released if it was reserved capacity previously. This mechanism, also, could use cards, however the CONWIP cards are not allocated a specified part (Fernandes, 2007).

Rother & Shook (1999) presented an approach to CONWIP that thye called FIFO lane. FIFO lane means a specific quantity of inventory located between supply process and customer process. This quantity is limited by a maximum that when reached this stops production of the supply process until customer process consumes material (Figure 2). The maximum is a way to control the WIP because when it is achive the production of that product has to stop.

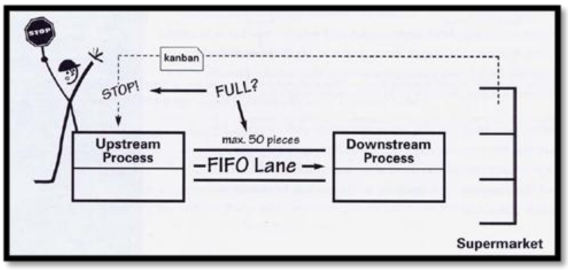


Figure 2 – FIFO lane representation (Rother & Shook, 1999)

In contrast with supermarket associated to Kanban System that has specific products in each position, FIFO lane has a total quantity of the supplying process, not being specific of a product (Overbeek, 2008).

3. Company products and problem description

This study was done in an electronics components company. Its main product had been car radios but since a few years ago that has enter in another business areas like heat boilers controllers and navigation systems, supplying others companies of the same owner.

The project developed was in the heat boiler controllers assembly lines. These assembly lines needed to improve efficient metrics and synchronism between the different subsystems: the PCB assembly lines and the final assembly cells which final product was the product of the Figure 3.

Figure 3 - Heat boiler controller

3.1. Characterization of heat boilers controllers assembly lines and cells

The area studied was composed by one manual assembly line and five final assembly cells oriented by family (Figure 4). The manual assembly line (blue rectangular in Figure 4) supplied the final cells (one purple, three green and one orange square). All cells were different and produced different products family, distinguished by the different colour of the arrow (representing the material flow).

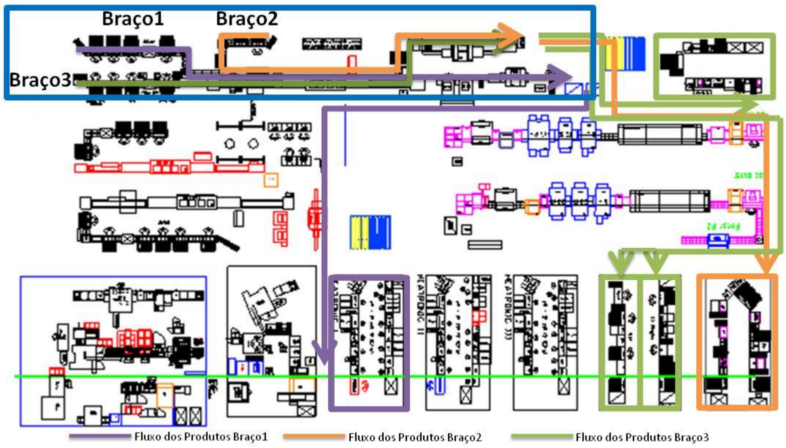
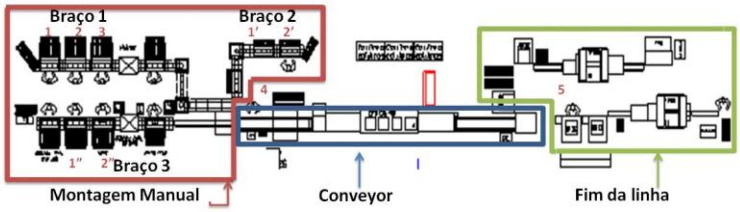


Figure 4 – Line and assembly cells layout and material flow

In the manual assembly line were inserted components in the PCB by female operators. The main components supplied were PCB and electronic components that were supplied by a milkrun. In the assembly line worked 9 operators, being mostly in the manual assemblies. They worked at three shifts (1286 minutes). The assembly line was split in three zones (Figure 5): manual assemblies (pink area), conveyor (blue area) and end of line (green area).

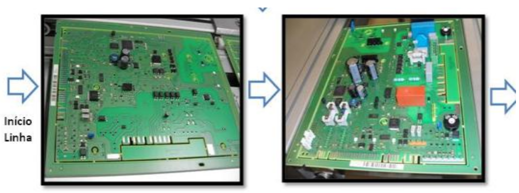


a) ....b) c)

Figure 5 – Assembly line zones: a) manual assemblies; b) conveyor c) end of line

The manual assemblies had three branches according the product family (eight families) with different needs of components. The PCB enters in this zone with the aspect of the Figure 6a). The conveyor was the zone of the assembly line where all PCB converge from the three manual assemblies. There was an operator at the beginning of conveyor that took the PCB and put it in a specific frame box. This frame box was essential to pass in welding machine because it was the support of the PCB. There were different types of frame box to each different PCB. This frame box circulated into the conveyor and then returned at the beginning. The frame boxes that were not being used were saved in a trolley.

The end of line was composed by a control test and a milling machine. After that, the PCB was completed and appears with the aspect of the Figure 6b) and put on a container. Usually, each container has 12 PCB. When it completed, the container was sent to the stock shelves. If it had not stock, the container is directly send to final cells.



a).........................b)

Figure 6- PCB: a) before the manual assembly line; b) after manual assembly line

3.2. Critical analysis

This section presents the critical analysis done to identify the problems in the assembly line. Initially, was done an ABC analyses in relation to quantity (P-Q analysis) because there was many different types of products to assembly in the line. It was essential to know which products were more important in daily production. Customers that buy a high quantity represent more sales and more profit to company therefore, these products must be the priority. The results of the P-Q analysis gave two A products: Heatronic and Regler.

After this, it was made a Value Stream Mapping (VSM) for one of the A 'products: the Heatronic. VSM is a good tool to represent the materials and information flow and help to identify activities that do not add value to the value stream. The Figure 7 shows the VSM for Heatronic family. With this tool was possible to verify pushed flows, many stocks in the end of the assembly manual and that the line was not levelled. The ratio between value added and lead time was 0,24%, a value very low and there was many improvement opportunities.

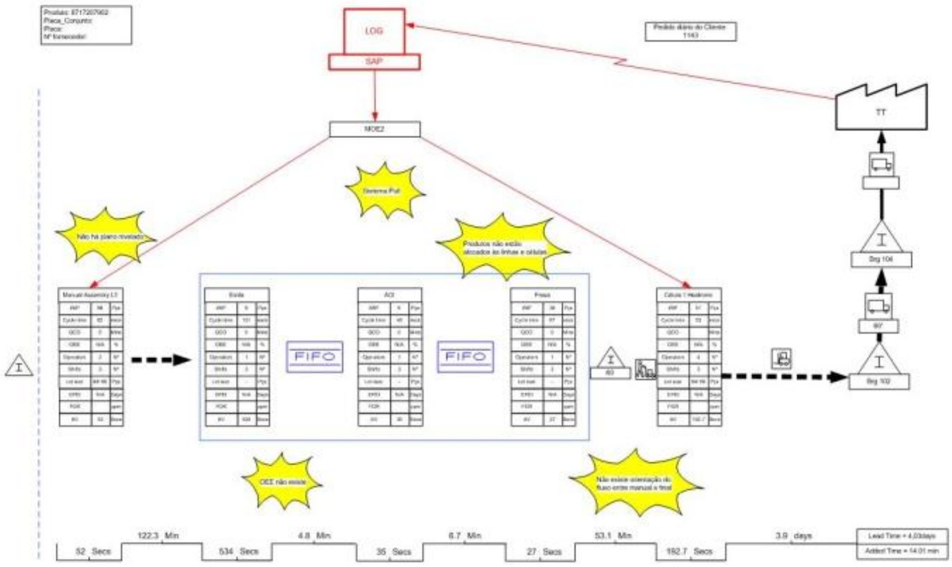


Figure 7 – VSM of the Heatronic family

3.2.1. Capacity analysis

An analysis done in this phase was the line capacity analysis to verify if the line had capacity to produce the weekly plan made by logistics department. Collecting some data like planned operation time of the line, quantities required, and line cycle time (CT), allowed calculate the line capacity. Then CT value was compared with customer takt time (TT). Therefore, the line CT was superior to the TT, unviable the planed quantity, so line had not capacity for 16% of planed quantity.

3.2.2. OEE analysis

Other metric calculated was Overall Equipment Effectiveness (OEE). OEE involves the calculation of 3 parameters (available, quality and velocity) but in this case only was measure with available parameter:

$$\text{OEE} = \frac{\text{Net production time (Number of finished parts} \times \text{CT)}}{\text{Planned operating time}}, (1)$$

Because there was not enough information to calculate velocity and quality parameters.

The conclusion of this calculation was that assembly line had low level of effectiveness. OEE was 80% (considering only the available parameter), means that in 20% of time was not productive. It was possible conclude that the line did not have capacity nor effectiveness.

3.2.3. Assembly line stops

During analyses of line, it was verified many stops of the line and it was necessary to understand the causes for this. This was made through a sheet created for the operator register the causes (why and how long the pause). This was done during two weeks. After this, it was produced a cause and effect diagram with all registered causes (Figure 8).

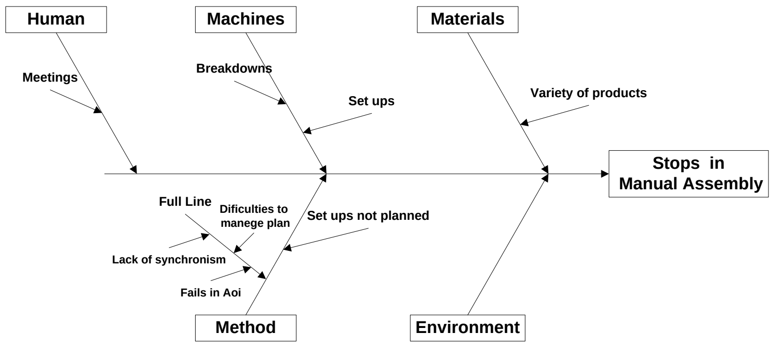


Figure 8 – Cause and effect diagram for stop manual assembly line

The conclusion was that line stop more times (corresponds 76% of stopping) because line was full of WIP due to have a critical workstation (bottleneck). This workstation was in the beginning of the conveyor and had always WIP. This workstation had a high CT. So, line stopped around 30 minutes per shift due to being full.

3.2.4. Bottleneck analyses

To have synchronism between manual assembly line and final assembly cells was essential stability in processes and minimizing fluctuation of bottleneck process. The bottleneck workstation identified in the previous section took PCB from conveyor to frame boxes (red circle in Figure 9).

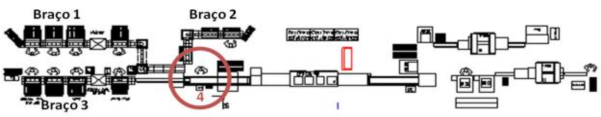


Figure 9 - Bottleneck workstation

Different PCB corresponds to different frame boxes. When each branch of manual assembly had a type of product change, all of frame boxes correspondent to before product had to take off from conveyor welding. This occurred a lot of times per shift and it was not planned. This workstation had other problem that was absent of standards and systematic. Operator had not a standard to put frame boxes in the welding conveyor and a defined sequence to put the frames boxes to circulate in conveyor. Many times the product did not match the frame box and operator had to take this off (Figure 10). This happened because manual assemblies' production was not synchronized with welding conveyor.

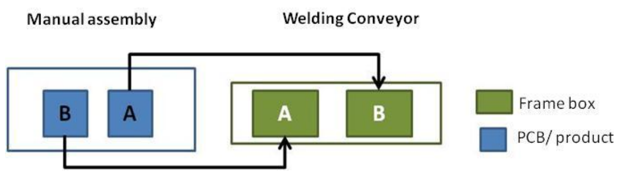


Figure 10 – Mismatch between manual assembly and welding conveyor

Unscheduled changes were a problem because operator wasted time in removing the wrong frame, increased CT and instability. If CT increases, planned CT will not be what was hoped, therefore line capacity decreased. It was measured the bottleneck CT during a week (Figure 11) showing the instability of this value. This is due to deviations like the unplanned changes of frames boxes.

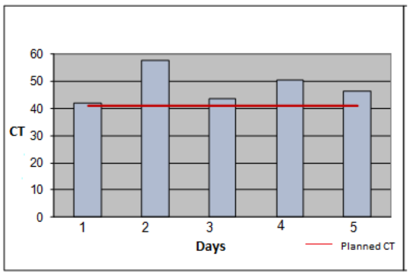


Figure 11 – CT (in seconds) during 5 days

Each time a product change was made, system only stabilized after 10 minutes.

3.2.5. Summary of problems identified

The most important problems found were:

- production planned was not fulfilment (missing 16% for fulfilment)
- OEE is 80% (20% lost)
- Final assembly cells without PCBs due to synchronism absent between two processes
- High WIP in the branches of manual assemblies and in the end of line
- Absent of standards in workstations
- Overstock in the final manual assembly without identification and wrongly allocated
- Make to stock for the following shifts
- Work tools and trolleys without identification

4. Proposals Presentation

This section presents some proposals proposed for the problems identified. Through value stream design (VSD) was draw a process more lean with less wastes.

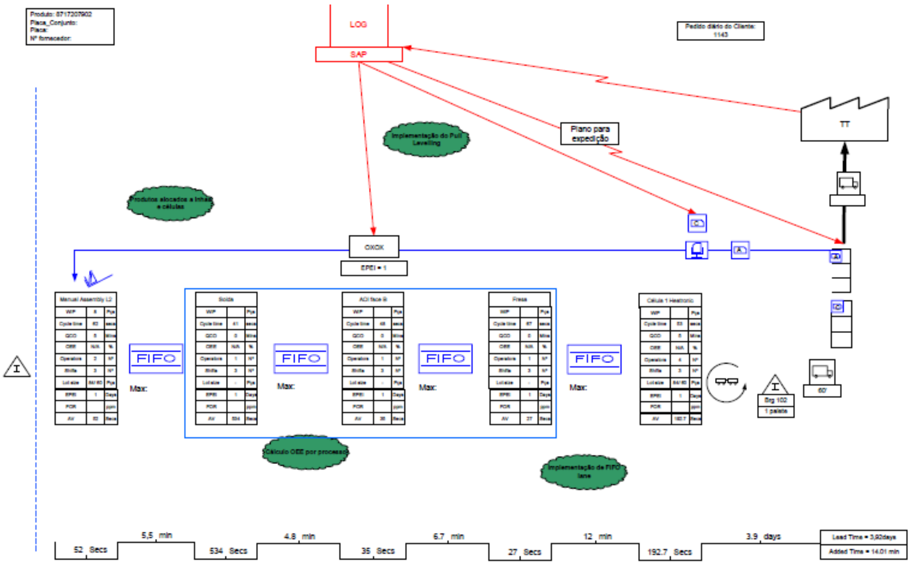


Figure 12 – VSD for Heatronic family

Such proposals were mainly, the implementation of a Pull system between the assembly lines and the final assembly cells. For achieving this was necessary first solve the problem of the sequence absent of frames box. So, was defined a sequence for matching the PCB with the frames box, reducing in this way the CT of the bottleneck. Additionally, was necessary to implement the Lean tools more basic like 5S, visual management and work standards.

4.1. Frames boxes sequencing and synchronism

To create synchronism between the manual assembly and welding conveyor was defined a frames boxes sequence. The frames boxes sequencing implied a five steps procedure: 1) calculate the total number of frames boxes in conveyor; 2) convert the quantities need in assembly line according the final assembly; 3) calculate the CT; 4) define the frames boxes number for each product family; and 5) create the frames boxes sequences for the different work shifts.

The application of this procedure gave a frames box sequence for each shift, being the figure 12 the sequence for the first two hours of the first shift.

Figure 13 - Frames boxes sequence for the first two hours of the first shift

In order to maintain these sequences was necessary implement some standards in the workstations and discipline using the 5S and visual management.

4.2. Work standards

For the sequences created was formulated a document, put on the bottleneck workstation to consult when had some doubts. In this document was information about the frames boxes quantity of each product family for the sequence and the position and identification in each frame.

Products	Identification of frame	Number of frames
Heatronic	9	7
KME/ Riboard	13/ 12	6
Regler	11/6	6

Figure 14 – Quantity of frames for each product

4.3. 5S's and visual management

5S was implemented in the trolley where the frame boxes are saved because there wasn't specific place to save each frame box and trolleys were always messy. This part of the line was the most critical in relation to 5S tools. The workers waste a lot of time to find a frame box that they wanted.

First, it chooses only the necessary frame boxes of the each product. All frame boxes that were not necessary were taking off of the line. After this, all frame boxes were numbered with number about the product and in the trolley had a place with correspondent number. It was more easy and quick to worker and to smooth the changing of products.

This part of the line was the most critical in relation to 5S tools.

4.4. FIFO lane

The definition of the FIFO Lane was dependent on the quantity consumed in the final assembly and manual assembly and it is achieved only with stability created by systematic of frames. Final assembly is an internal costumer of manual assembly and this will only produce when final assembly requires. Therefore the final assembly pulls the production. It is important to remember that the creation of a FIFO Lane was necessary because the line must produce other products and it was necessary having some stock between the two processes to avoid line stops. The calculation of PCB need between processes was made through the next equations and table 1 present the results of calculations.

$$\text{Available time} = \text{Production time} - \text{Not production time} \quad (2)$$

$$\text{Number PCB Need.} = \frac{\text{Production time} - \text{Not production time}}{\text{TC MF}} \quad (3)$$

$$\text{Number Containers Need} = \frac{\text{Number PCB need}}{12} \quad (4)$$

Table 1 – Quantity of products in FIFO line

Products	Equation 2	Equation 3	Equation 4
Riboard	86	55,7	5
Regler	130,9	51,5	5
CAE	N/A	N/A	5
Nefit	408,2	270,6	11
RVC	N/A	N/A	6
IXM	389	75	4
Trim-Mid	N/A	N/A	23 × 2

The space for FIFO lane was dimensioned and is presented in Figure 15.

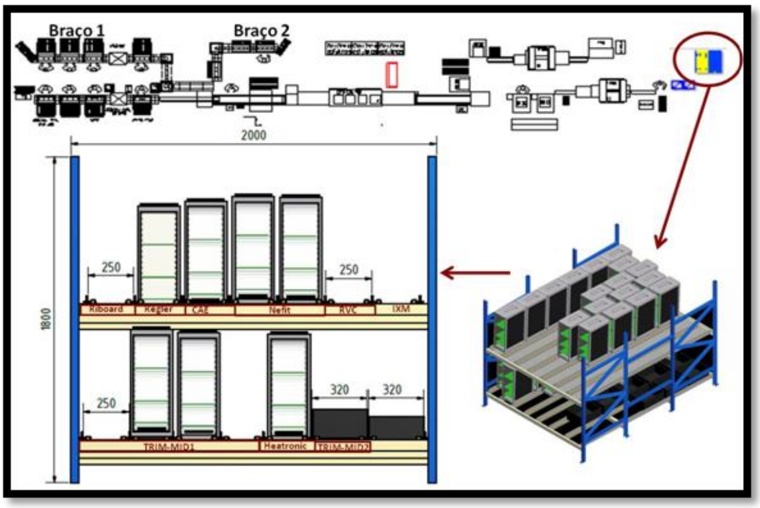


Figure 15 – FIFO lane

5. Results presentation and discussion

The most important result of this work was the stability of bottleneck process. The cycle time became more stable and changes of frames were decreased. Figure 16 shows the cycle time stability before and after implementation.

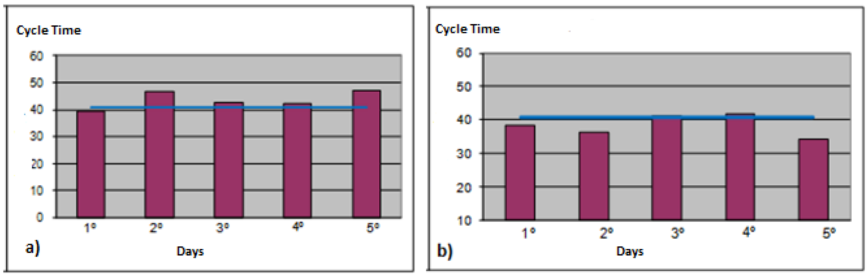


Figure 16 –Cycle time a) before implementation b) after implementation

However, other improvements were very important and the gains are presented in Table 2.

Table 2 – Resume of improvements

	Before	After	Gain (%)	Gain (€)
CT bottleneck (sec)	**Variable**	**20,4 sec**	**-**	**-**
Standard deviation (in relation to planned CT)	**24,07**	**14,38**	**40**	**6840**
Space (m2)	**9,86**	**3,82**	**61**	**731**
OEE (%)	**80**	**90**	**10**	**5320**
Change over time (min)	**10**	**2**	**80**	**1920**
Change over time not planned	**21%**	**1%**	**20**	**-**
WIP max (containers)	**216**	**72**	**67**	**-**
Fulfilment	**16%**	**8%**	**50**	**1960**
Lead Time (days)	**4,03**	**3,92**	**3 (2h)**	**4800**
Distance(m)	**40**	**25**	**37,5**	**-**
Transport time (sec)	**80**	**50**	**37,5**	**-**
				21.771

Example: 10% Gain in OEE represents 45minutes of production, which represents 131 products

6. Conclusion

The main objective of this dissertation was to implement a Pull system between PCB manual assembly line and final assembly cells of boiler controllers to create synchronization between the two subsystems and obtain a continuous PCB supply. To achieve this goal was necessary understand which were the problems and weaknesses of the production system. Thus, after careful observation of what was going on line and analyzed the information existent, it was developed a critical analysis of the line, using some tools Lean. An important tool to recognize opportunities for improvement in line was the VSM that was also allowed to better understand the processes and material flow in the line. Thereafter, this analysis permitted conclude that the level of WIP in the line was one of the problems. Other problem was a critical workstation that limited the whole process, the bottleneck.

The technique FIFO Lane was reviewed and developed to synchronize two processes that were not physically connected. The creation of the FIFO Lane involved calculation of a maximum stock level that limits the amount of production, that is, when it reaches the limit, production will stop producing the product in question. The creation of this reduces the stock between the two processes, necessarily reducing the space occupied.

The waste reduction was achieved through various techniques: 5S and visual management. Of the seven wastes,, the most significant in terms of reducing waiting times were unnecessary movement and that directly affecting the efficiency of the line. The time gained in this affected the time available to produce, thereby increasing the OEE 10%.

Finally, it was possible to conclude that the technique FIFO Lane is suitable for connecting processes which cycle times are approximate. In this case, the technique has proved successful in spite of some processes had different cycle times and a lot of instability.

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