Development of a New Assembly Line, with Application of Lean Methodology

Manuel Maria de Albuquerque d'Orey Cortes

Department of Engineering and Management, Instituto Superior Técnico, Universidade de Lisboa

January 2021

Productivity is a transversal challenge to any organization in the production sector. Due to the fact of combining human factors with machines, an assembly line has an added complexity. With the constant technological advances, the manufacturing industry is becoming increasingly competitive, demanding its players to increase their standards. Higher quality product, low costs and customization are some of the decisive factors for the success in this industry. In the case presented, the product is high-end coffee machines, a product whose assembly carries enormous complexity while its market demands levels of efficiency and productivity that are difficult to achieve. This case study consists in a thorough analysis, performed by the Kaizen Institute in partnership with its' client, that aims to develop a new assembly line for a renowned coffee machines productor.

Key Words: Lean methodology, production flow, process efficiency, time and task analysis, setup.

1. INTRODUCTION

In order to increase productivity and reduce manufacturing costs, Company X contacted the Kaizen Institute Consulting Group (KI) to, through Lean methodologies, develop a new assembly line capable of achieving the desired metrics. The new assembly line should have the capacity to produce several models, with different specificities, without incurring in losses of availability, caused by lengthy model changes or setups. This dissertation aims to present a real case study in which, through a developed methodology, inspired by the literature and in past case studies, sought to solve the problems associated with the development, from the beginning, of an assembly line of a company.

2. CASE STUDY

Empresa X

Founded in the 1970s in Switzerland, Company X started by producing household appliances, more specifically waffle machines and toasters. The company grew and in 1978 founded its first production line, dedicated to the assembly of coffee machines. The growth continued, and by the end of 1989 the company opened Portuguese factory, in the country's western sub-region. Currently the company produces approximately six hundred thousand coffee machines per year, with prices between 500 and 1500 Euros.

Kaizen Institute

The Kaizen Institute Consulting Group (KICG) is a multinational company, founded in 1985 in Switzerland, which provides consulting services. KICG is a pioneer and leader in the implementation of Kaizen Lean tools. The word Kaizen comes from two Japanese words: Kai, which means to change and Zen, which means better, and which together result in Kaizen.

2.1 Line 3

Production is the main area of Company X, to which they allocate most of their human, technological and financial resources. The assembly area has a total of 5 assembly lines responsible for the production of the coffee machines, that are then sold to 3 major clients. Each production line works in exclusivity for a given client.

The project aimed to design a new line that would produce the same models as the current line 3. Line 3 is divided between the main line, which guides the production pace, which has the largest number of assembly stations and where the machine starts and ends its assembly, and the pre-assembled lines, smaller lines parallel to the main one, where some components are assembled, and then introduced along the line.

The line is supplied by a logistic train that supplies itself in a component supermarket. Company X has an injection zone in its facilities, which means that most of the components used in the assembly of the machines are produced internally.

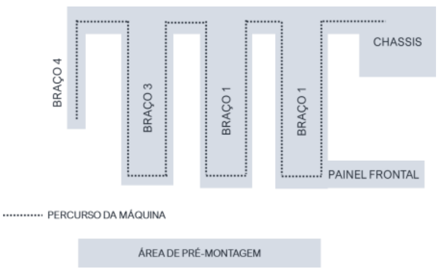

Figure 1 - Initial state: Line 3

2.2 Introduction to Kaizen Time Study

KTS is an innovative video analysis tool that aims to simplify the assembly process's video analysis. With the implementation of such a tool a company can save both time and resources in this process.

2.3 Problem categorization

The objectives of the methodology, and the metrics that will be used to assess its viability in the case study are:

1. Streamline the process of analyzing times and tasks by implementing and training those responsible for the task of the KTS tool.
2. Develop an assembly line with a productivity 30% higher than the current line 3,
3. Create a culture of sustained continuous improvement within the organization.

3. STATE OF ART

3.1 Lean

Lean Manufacturing, or Lean Production is a multifaceted production approach capable of understanding a wide variety of industrial practices. This approach is directly oriented to the identification of what is adding value from the customer's point of view and, once the value is identified, enhancing the flow of these processes.[1] Basically, the main objective of Lean is to be able to create a process flow that from the initial phase to the finished product, it is composed only (or almost) of added value tasks.[2] [3]

3.2 Lean thinking

The big principle is to reduce waste. The waste to be effectively eliminated must be identified and recognized as such. One must identify who is responsible and finally analyse it in terms of size and impact. Waste that is not identified cannot be removed. According to the authors Womack and Jones (1998) there are seven types of waste, or "changes", a Japanese word that means "no added value" or "waste". As far as *Muda* is concerned, it is divided into seven types: People's Movement, Material/Information Movement, People Waiting, Material/Information Waiting, Over Production, Over Processing and Mistakes [4].

3.3 Tools and concepts of lean

Visual Management

Visual Management is a communication strategy often observed in Lean environments that seeks to improve the performance of organizations through a communication and visual management systems. Once you make problems visible, solving them is easier. [5] [2]. One of the standards of Visual Management are the 5S, developed in 1950 at Toyota with the aim of creating habits that improve the organization and tidiness of the workplace. [6] The 5s correspond to five Japanese words, each with an action meaning, and must be used in a specific order. The 5S are: **Seiri** (Sorting), **Seiton** (Tidying), **Seiso** (Cleaning), **Seiketsu** (Normalization), **Shituke** (Discipline)

Value stream mapping (VSM)

Lean Production Movement [7] developed and presented the V*alue Stream Mapping* (VSM) tool, that seeks to reorganize and improve the production system [8]. In their study on Value Chain Mapping and Waste Reduction, Rother and Shook (2003) defined five fundamental steps for implementing a VSM: Gathering Information, Mapping the Current State, Identifying Root Causes of Found Waste, Mapping of the Future State, Defining the Work Plan, Executing the Work Plan

Root-cause analysis

Decision making and problem solving are transversal actions to any organization, and the use of tools for this purpose are great way to face these challenges. One of the existing tools is the *Ishikawa* diagram, widely used in the industrial environment, mainly in quality areas.[9] The Ishikawa Diagram is a tool that helps to identify the root causes of a problem. [9]. The causes are usually grouped into 6 major categories, divided between the transversal "bones": People, Method, Machines / Equipment, Material, Measurement, Environment

3.3 TFM – Total Flow Management

3.3.1 "U" layout

In a study by Schonberger (1982), he noticed that unlike American lines, whose assembly lines were arranged in a straight line, Japanese factories had theirs in a layout similar to the letter U.[10] According to the study by Ullah Saif (2014), one of the great advantages of this layout is the the flexibility that it has, thanks to the proximity that exists between the two ends of the line. In addition, a U line significantly reduces the movement of operators (they operate inside the line), WIP (Work In Progress, or Semi-Finished Product) and handling of the inventory, thus increasing productivity. [11][12]

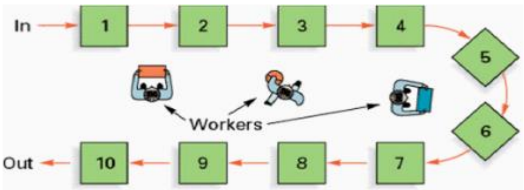

Figure 2 - "U" shaped Layout

3.3.2 Line Balancing

The goal of balancing is to assign a set of processes to the various workstations, ensuring that there are no disparities between them and that the maximum cycle time does not exceed the calculated takt time.[13].

- Takt time is defined as the "time available for production in a period of time / demand from customers in the same period. [14]

- The cycle time is defined as the time taken to execute a process.[15] The execution starts from the moment the operator starts the assembly process until the machine is transmitted to the next phase.

Once the times and the number of stations are established, the balancing begins with a Yamazumi chart. This graph shows the load, in terms of duration, of each station.[16]

3.3.3 Standard work

Standard Work, is a set of procedures that seek the best combination between the worker's actions and the specifics of the equipment, in order to achieve the best levels of efficiency, productivity, quality and safety possible. [17] Standard Work establishes a starting point and a reference on how to perform a given task, ensuring higher levels of productivity and fewer waste.[18]

3.3.4 SMED

The purpose of this tool is to minimize the time spent on setup. The shorter the setup time is, longer the time available for production, so it becomes especially important to reduce it to the maximum.[19] A study by Abraham, Ganapathi and Motwani (2012) developed a methodology for the SMED that is divided into 7 steps: 1-Separate the external activities from the internal ones; 2-Standardize External Activities; 3-Convert External Activities into Internal Activities; 4- Reduce the time of internal tasks; 5- Reduce the time for external tasks; 6-Standardize the tasks; 7- Eliminate the Set-Up. [20]

3.3.5 OEE

Presented by Nakajima (1988), OEE is one of the main indicators used to control the performance of an equipment in a production system. OEE is an especially important indicator in production and assembly companies, as it measures the total efficiency of production, in relation to its theoretical capacity. OEE makes it possible to identify losses in efficiency at three levels, availability, performance and quality. [21]

$$\boldsymbol{EE = Availability \times Performance \times Quality}$$

Equation 1 – OEE Calculation Formula

Availability - Is the comparison between the amount of time the machine is producing and the amount of time it was scheduled to produce**.**

Performance – ratio between the actual quantity of units produced and the theoretical quantity of units that can be produced in the actual operating time of the equipment.

Quality – ratio between the number of units with acceptable quality for sale and the total number of units produced.

3.3.6 Pull planning

The Pull Planning System is one of the fundamental pillars of Lean philosophy. The great difference of this system to the traditional Push system is that in the second, production is triggered by demand, that is, a certain amount is produced for real demand, while in the second, production is made based on forecasts and history demand.[22]. This system is also called Just-in-Time.

4. CURRENT STATE ANALYSIS

n this chapter, the study carried out on company A is presented, the main origins of the problems currently found in the company, and the effects they cause on the operation.

4.1 Kaizen event: VSM

The VSM of Company X was held at a Kaizen event and lasted for three days. The VSM was applied in three distinct and consecutive stages: 1) mapping the current status of Company X; 2) identification of the root causes of the identified waste; 3) mapping the future status of Company X.

Mapping the current state of Company X:

All processes were mapped from the arrival of the raw material to the departure of a fully manufactured FACM. The value chain of the coffee machine is divided into X major moments: Reception, transformation (injection), storage, assembly and shipping. In the figure below is the result of the mapping performed to the main component of the machine, the chassis.

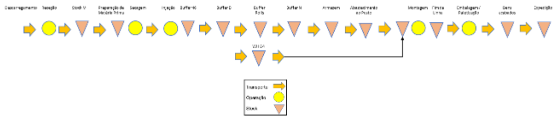

Figure 3 - VSM

Root-cause analysis

A deeper analysis was made to the causes of the problems identified in the assembly area. Most of the wastes identified were related with Inventory (too much production for intermediate stock and WIP between line stations), Defects (Machines with defects that are reworked after being assembled), Movements of people and material (a lot of waste due to the excessive movement) and long waiting times.

To better understand the root causes of these problems, an Ishikawa diagram was used. The main conclusion is that most of the waste identified was due to 5 factors: Lack of Standards; Lack of Balance; Non-Optimized Line Edges; Pre-Assembled Away from the Main Line; Lack of Indicators

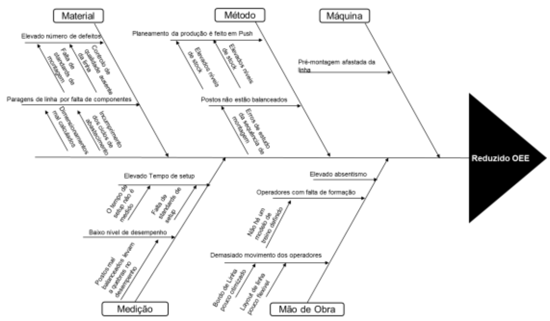

Figure 4 - Ishikawa

Future state mapping and implementation strategy

After a deeper study of the origin of these problems, it became clear what would be the way forward to solve them. The strategy was divided into 3 major blocks:

1. Streamline the Time Analysis Process, using the KTS application

2. Develop a Flexible Assembly line, through the principles of U-layout, reduction of setup times, creation of Assembly Standards and balance of the stations.
3. Sustained improvement, through the creation of daily meetings, 5S and PDCA improvement cycle.

Goal setting:

In the analysis made to the current state, a series of indicators were calculated. These same indicators would serve as baseline to establish objectives and evaluate the impact in the future. The initial indicators and are objective in the table below:

Table 1 - Goals

Indicator	Baseline	Goal	Gap
Time for Video analysis	**40 days**	**15 days**	**-62,5%**
Occupied Area	**400m^2**	**350**	**12,5%**
OEE	**73,3%**	**85%**	**11,7pp**
Setup	**33min**	**90 seg**	**95,5% (31,8min)**
Productivity	**9,7**	**12,6**	**2,9pp**

5. STRATEGY IMPLEMENTATION

5.1 KTS implementation and training

The implementation of the KTS application was done in a full day session. The objective of this session was to train the GSI team, so that in the end they would be able to integrate the application with the real case of the assembly line. This session was attended by the Kaizen team (trainers), members of the GSI and the production manager. The training method was the TWI (Training Within Industry).

All the features of the application were taught, starting with the analysis of the video and division into tasks, the classification of tasks as being MUDA or added value, and finally the Balancing of stations, where the takt time was calculated and the tasks were rearranged according to the desired cycle time.

The final feedback was very positive and the whole team was motivated to apply the knowledge to the project.

5.2 Development of the assembly line

This chapter explains the various steps in the development of the assembly line. The main objective of the project is to build a new line for Company X, a flexible line, based on Lean principles and that can achieve exceptional results at a low cost.

5.2.1 Takt time calculation and number of stations definition

Data for the year of 2021:

- Production objective = 110 000 un.
- Number of labour days = 200 days
- Work Schedule = Single shift of 7h40 (without pauses)

This means that in order to achieve the established goal, it would be necessary to produce an average of 550 machines per day, with an opening time of 7:30 am which corresponds to 27600 seconds of production time, or opening time. With this information, all the conditions are met to calculate the takt time. Using the formula proposed by Lam (2016) (Equation X), a takt time of 50 seconds was calculated.

$$Takt\ time = \frac{Working\ Time}{Daily\ production\ needed\ to\ meet\ demand}$$

When defining the cycle time of the line, inefficiencies must be considered. For this reason, a 50 sec cycle time should not be programmed, as this would hardly be accomplished. Considering an OEE of 85%, a cycle time value of 43sec was defined. With this cycle time, the number of stations in the line was calculated. Since the total production time of model A machines is 22 minutes, corresponding to 1320 seconds, resulting in 31 jobs. For model B, the time is 21 minutes and the number of stations 30. These times only correspond to the main line, ignoring all the pre-assembled ones that are directly supplying the line.

5.2.2 Line balancing

Process divided into 4 steps:

Step 1: Filming of the assembly sequence

The first step was to film the complete assembly process. These shots were taken on line 3, as it was the one whose new line was to be replaced.

Several shots were made for the same station, in order to identify the most critical tasks, whose variability was greater.

Step 2: Assembly Sequence Analysis using KTS

By clicking with the mouse on the video, the assembly process was separated in all tasks. It was at this stage that value added tasks and waste tasks were analysed. For the second, attempts were made to find solutions for improvement. At the end, all tasks are listed, with real time and useful time (without MUDA).

Step 3: Creation of the Process Graph

After analysing the assembly sequence, the Process Graph is created. In this graph, in addition to showing the entire assembly sequence in a visual way, the components used are also detailed.

Step 4: Line Balancing and Yamazumi Graph

The KTS application has a feature for balancing stations. Just enter the cycle time and the number of stations, which automatically creates a bar graph, one bar for each station. The next step is to distribute the tasks among the posts. It is a difficult and meticulous process as it is necessary to guarantee the fulfilment of the precedence between tasks, while respecting the cycle time.

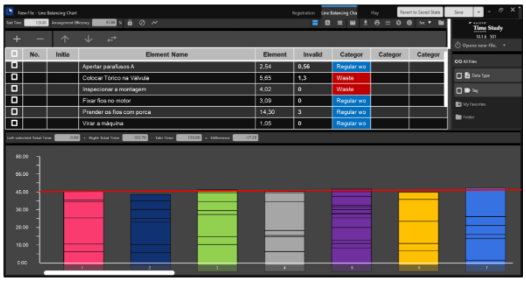

Figure 5 - Line balancing on KTS

This whole process is done in an iterative way. Meaning that throughout the development of the line it is quite common to adjust the times of the tasks, the posts and the sequence itself. Especially during the mockup phase, it is common to rebalance and redefine jobs.

5.2.3 Mockup

It is at this stage that the entire study previously carried out is tested and validated. In the mockup phase, the final sequence of the assembly and the general appearance that each station must have must be defined. Which includes all the necessary tools, the various benches that will support the component boxes and the border of line. The mockup phase was divided into two stages.

Step 1. Construction of a line replica

One must try to recreate the same conditions as the line, so that the results that come out of this phase are as close to reality as possible. Thus, the first step is to build a replica of the line, with the same material, the same shelves and the same conveyor belt that will shape the future line.

Figure 6 - Line replica used for the mockup

Step 2. Stations Validation and Assembly Sequence

The next phase consists of, in an iterative way, testing, changing and validating the assembly sequence and defining component positions at the line edge. This validation is done by an experienced operator on the line.

The process was carried out point by point. For each station, the assembly sequence established in the previous phases was tested. The focus was on observing the movements performed by the operator and seeking to identify inefficiencies in their movements and ways to make the border of line more optimized. After optimizing the border of line and the operator movements, three hypotheses could arise:

1- The first hypothesis is **that the station has the expected cycle time**. In this case, the post would be considered finished and the next one would begin.

2 - The second hypothesis is that the station **has a cycle time shorter than the expected**.

For these cases, the following stations were used to "pull" tasks in order to guarantee the desired assembly time

3 - The last hypothesis is that **the duration is above the desired cycle time**. In this case, tasks should be eliminated or exchanged with other stations in order to ensure balance.

5.2.4 Internal Logistics: Dimensioning the BOL

The operator's role is to carry out the assembly process, and the entire operation, both upstream and downstream, must be directed towards this moment. For this reason, everything that is extra assembly operations must be outsourced and never carried out by operators. Of course, the border of line requires management. The space is not infinite, and the component boxes do not come directly from the suppliers in the same way that they will later be arranged in there. This requires not only a border of line **replacement activity**, but it also requires a **repacking activity**. The first one to guarantee the continuous supply of the line, trying as much as it can to never stop for lack of material, and the second to guarantee that the packaging of the material comes in the same format and quantity that will be stored at the border of line.

This replacement is carried out by means of a logistical train, which in the Lean vocabulary is called *Mizusumachi*, or just Mizu. Mizu operates between the component supermarket and the assembly line, and is responsible for collecting the empty boxes and replacing the boxes with components. The boxes function like Kanbans, and as soon as one is empty, it triggers a replacement order. Its cycle starts at the first station and goes through the entire line, simultaneously collecting the empty boxes (stored in the replacement area, ready to be collected) and replacing all the components collected in the previous cycle. Then he goes to the supermarket to replace all the components whose box he removed from the replacement areas of the service stations.

The duration of the mizu cycle is 20 minutes, which means that the duration between picking up a box and replacing it takes approximately that duration. It has to be ensured that the quantity of each component in line must have sufficient autonomy to withstand the cycle time of the mizu. The dimensioning of the number of boxes of a component on the border of line must be done considering the worst case scenario, that is, for a scenario in which the mizu passes through the station in the instant immediately before the end of a box.

For this reason, a metric was established according to the following formula:

$$\# \, boxes \, on \, the \, BOL = one \, cicle \, consumption * 2 + 1 \, safety \, box$$

5.2.5 Line construction

After the BOL mockup and dimensioning phase, the conditions are met to start the construction of the line. Before the line is "physically" built, 3D design is made using software suitable for this type of infrastructure. This design is made according to the parameters calculated in the previous phases, that is, the position and the location of the components must be the one that, during the mock phase, is concluded to be the most efficient. The drawings and details of each station are sent to the engineering team, who will manufacture them. The material used is trilogiq, known for its flexibility and robustness. The entire assembly phase was done with the internal engineering team who, thanks to the experience of the past lines, were quite used to working with this type of material.

5.2.5 Line Ramp-up and Follow-up

In order to start the line as efficiently as possible, a control and monitoring system was implemented. The most important indicators were identified and every day the team met and analysed the previous day. The line's growth curve was also monitored, and the line's rhythm was adjusted every day to accompany this growth.

The training of operators was carried out according to the TWI methodology. Many of the operators were new and had never been in an identical assembly environment, which was quite a challenge.

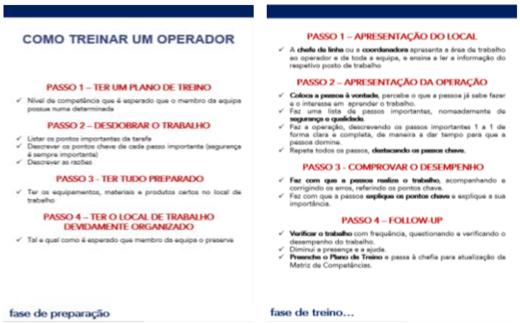

Figure 7 - Training model (TWI)

Throughout the start-up period it was necessary to make adjustments to the stations and changes to the assembly sequence. A proof that no matter how much work is done in the preparation phase, the human factor always has a say.

In order to monitor progress and identify stations with a greater or lesser load, a system of service audits was developed. This system consisted of a form, where in addition to having several questions about the line edge (whether it was optimized or not) and ergonomics, three measurements of the assembly time of the station should also be introduced. This form was linked to an excel file, which contained a dashboard with indicators that was updated each time a new form was submitted. The dashboard is presented below:

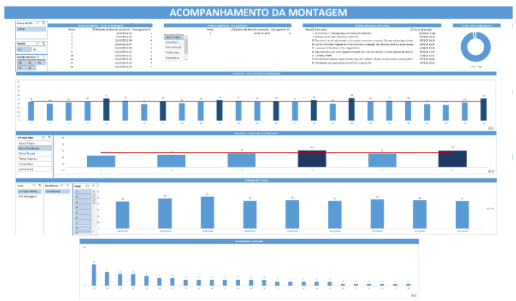

Figure 8 - Follow-up dashboard

5.2.7 SMED

To correct the problem of high setup time, a SMED was performed. Through the creation of standards and visual management, it was possible to significantly reduce the duration of the setup.

5.3 IMPROVEMENT SUSTAINABILITY

Some actions were implemented so that the improvements achieved were not only sustained, but also that they served as a launching pad for a culture of continuous improvement in the company. The main actions that stand out are the Kaizen Daily meetings and the PDCA improvement cycle.

6. RESULTS

The final balance of the project is extremely positive. In all indicators, the impact of the actions implemented was positive.

6.1 Video analysis

Given the urgency of the line, it was crucial to speed up the preparation phase, but without ever compromising the quality of the line. One of the ways to make the preparation shorter was through the KTS app, which allowed the team to carry out a work that in the past took about 2 months, approximately 45 days, in 15 days.

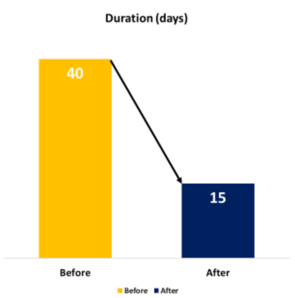

Figure 9 - Duration of video analysis

6.2 Setup

Through the SMED approach the setup time had a significant reduction. In the end the duration went from a long 33 minutes setup, to significantly shorter of only 200 seconds. This value represents a great reduction, but the team believes that it can go even shorter, to 90 seconds.

6.3 OEE

One of the most important indicators is the Overall efficiency of the Line. The previous value was about 73,3%, with several losses due to long setups, poor performance from the operators and lack of balancing between stations. After 2 months of productions the OEE reached 86.7%, a difference of 13,4 percentual points. The details of the OEE it's available on the table below:

Table 2 - OEE final standings

Indicator	Baseline	Final Value	Gap
▪ Availability	86,5%	94,3%	+ 7,3pp
▪ Performance	91%	95,2%	+4,2pp
▪ Quality	93,3%	96,5%	+3,2pp

▪ **OEE**	73,3%	86,6%	+13,3pp

6.4 Productivity

The main indicator of the project was the productivity. The baseline was established on 9,7 machines per operator. Through the improvement of OEE, standard work and line balancing, the final value was 14,3, a significant improvement. It is possible to understand better the evolution on the picture bellow.

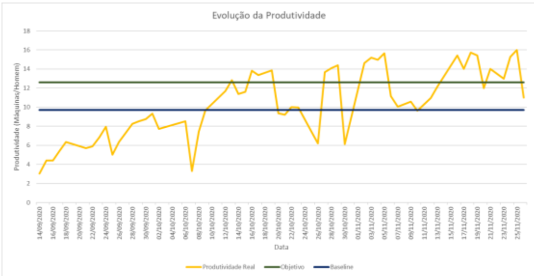

Figure 10 - Productivity evolution

6.5 Area

Thanks to the new line layout, in a form of a "U", its area was reduced from 400m² to 360m²

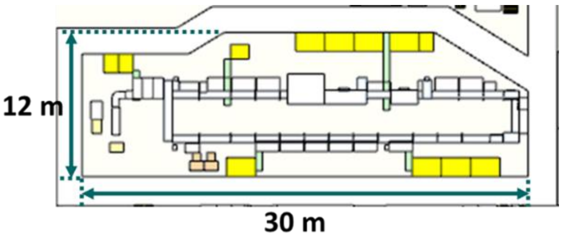

Figure 11 - Line 12 layout and area

6.6 Resume

In the image bellow, one may find the resume of all the results.

Table 3 - Project results

Indicator	Baseline	Final Value	Gap
Time for Video analysis	40 days	15 days	**-25 days**
Setup	33min	200 seg	**-90%**
OEE	73,3%	86,7%	**+13,4pp**
Productivity	9,7	14,3	**+47,7%**
Occupied Area	400m²	360m²	**-9%**

7. FUTURE WORK AND CONCLUSIONS

The main conclusions that can be retrieved from this project are:

- the importance of involving the entire hierarchy of the company in the implementation and sustainability of the improvement culture
- the benefits that Lean thinking brings to any organization
- SMART objectives should be established

As future work, 2 major areas of action are presented:

The first objective is to improve the setup time. Through the SMED, it was possible to reduce the model change time by 90%, to 200 seconds. Despite the improvement, the team still believes that it is possible to reduce more, to values close to 90 seconds.

An action that, despite not being a priority, should be considered, is the bet on 4.0 industry technologies. With technological advances the alternatives are getting better and many of the manual tasks existing today can be replaced by machines or RPAs.

References

[1] M. Holweg, “The genealogy of lean production,” *J. Oper. Manag.*, vol. 25, no. 2, pp. 420–437, 2007.

[2] R. Shah and P. T. Ward, “Defining and developing measures of lean production,” *J. Oper. Manag.*, vol. 25, no. 4, pp. 785–805, 2007.

[3] A. Sanders, C. Elangeswaran, and J. Wulfsberg, “Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing,” *J. Ind. Eng. Manag.*, vol. 9, no. 3, pp. 811–833, 2016.

[4] J. C. Chen, Y. Li, and B. D. Shady, “From value stream mapping toward a lean/sigma continuous improvement process: An industrial case study,” *Int. J. Prod. Res.*, vol. 48, no. 4, pp. 1069–1086, 2010.

[5] A. Tezel, L. Koskela, and P. Tzortzopoulos, “Visual management in production management: A literature synthesis,” *J. Manuf. Technol. Manag.*, vol. 27, no. 6, pp. 766–799, 2016,

[6] M. Imai, *Gemba Kaizen: A Commonsense Approach to a Continuous Improvement Strategy*, 2nd ed. ew York City: McGraw-Hill, 1997.

[7] B. J. P. Womack and D. T. Jones, “The machine that changed the world: By James P. Womack, Daniel T. Jones, Daniel Roos,” *Bus. Horiz.*, vol. 35, no. 3, pp. 81–82, 1992.

[8] I. S. Lasa, C. O. Laburu, and R. De Castro Vila, “An evaluation of the value stream mapping tool,” *Bus. Process Manag. J.*, vol. 14, no. 1, pp. 39–52, 2008.

[9] L. Liliana, “A new model of Ishikawa diagram for quality assessment,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 161, no. 1, 2016,

[10] R. J. Schonberg, *Japanese Manufacturing Techniques*. 1982.

[11] J. Miltenburg, “U-shaped production lines: A review of theory and practice,” pp. 201–214, 2001, [Online]. Available:

[12] D. Ogan and M. Azizoglu, “A branch and bound method for the line balancing problem in U-shaped assembly lines with equipment requirements,” *J. Manuf. Syst.*, vol. 36, no. February 2015, pp. 46–54, 2015,

[13] R. Pulkurte, R. Masilamani, S. Sonpatki, and R. Dhake, “Cycle time reduction in assembly line through layout improvement, ergonomics analysis and lean principles,” *J. Appl. Sci. Eng. Res.*, vol. 3, no. 2, pp. 455–463, 2014,

[14] B. J. Schroer, “Simulation as a Tool in Understanding the Concepts of Lean Manufacturing,” *Simulation*, vol. 80, no. 3, pp. 171–175, 2004,.

[15] Y. Kazuhiro, “Implementation of lean manufacturing process to xyz company in minneapolis area,” 2004.

[16] A. N. Adnan, N. A. Arbaai, and A. Ismail, “Improvement of overall efficiency of production line by using line balancing,” *ARPN J. Eng. Appl. Sci.*, vol. 11, no. 12, pp. 7752–7758, 2016.

[17] A. Pereira *et al.*, “Reconfigurable Standardized Work in a Lean Company - A Case Study,” *Procedia CIRP*, vol. 52, pp. 239–244, 2016,

[18] T. P. D. Team, *STANDARD WORK FOR THE SHOPFLOOR*. 2002.

[19] R. McIntosh, G. Owen, S. Culley, and T. Mileham, “Changeover Improvement: Reinterpreting Shingo’s ‘SMED’ Methodology,” *IEEE Trans. Eng. Manag.*, vol. 54, pp. 98–111, 2007,

[20] A. Abraham, K. N. Ganapathi, and K. Motwani, “Setup Time Reduction through SMED Technique in a Stamping Production Line,” *SASTECH J.*, vol. 11, no. 2, pp. 47–52, 2012.

[21] P. G. Yazdi, A. Azizi, and M. Hashemipour, “An empirical investigation of the relationship between overall equipment efficiency (OEE) and manufacturing sustainability in industry 4.0 with time study approach,” *Sustain.*, vol. 10, no. 9, 2018,

[22] C. C. Y. Tsao, J. Draper, and G. A. Howell, “An overview, analysis, and faciliation tips for simulations that support and simulate pull planning,” *22nd Annu. Conf. Int. Gr. Lean Constr. Underst. Improv. Proj. Based Prod. IGLC 2014*, vol. 1, no. 208, pp. 1483–1494, 2014.