Implementation of Lean Manufacturing to Increase the Machine's Availability of a Metalworking Company

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Abstract

The main objective of Lean Manufacturing tools is to eliminate waste from a process in order to make it more efficient. In this applied research with a quantitative approach, the production process of a steel coil cutting machine (Slitter) of a Peruvian metalworking company is analyzed. It can be said that the Slitter is indispensable to supply semi-finished products to a steel tube production line. Likewise, improvements are proposed and implemented based on three lean manufacturing tools in order to increase their availability, which hardly exceeds the value of 60%. One of the tools implemented was the single minute exchange of die (SMED), which is aimed at reducing machine preparation times (setup) by reorganizing internal to external activities. Another tool used was Kaizen, which seeks continuous improvement and standardization of processes through simple and concrete actions. Finally, the 5s method was applied to improve the cleanliness and order of the work areas. After these, the time available to produce increased 95.73 hours per month, which means an improvement of 17.36% in machine availability. Also, setup times and operation cycle times were reduced by 16% and 16.35% respectively.

Keywords
Lean, manufacturing, availability, SMED, kaizen, 5s.

1. Introduction
The incipient development, mainly technological, has led to low competitiveness in organizations in Latin America and the Caribbean. Underdeveloped or developing countries such as Peru allocate a very small part of their total budget to the area of research and development (R&D) (Inter-American Development Bank, 2016). According to the Inter-American Development Bank (2016), "the labor productivity of innovative companies in Latin America is, on average, 50% higher than those that do not innovate". For this reason, given the lack of investment in R&D in some organizations, it is essential to adapt and implement lean manufacturing tools in order to increase their competitiveness (Wilches et al. 2013). The lack of production processes that use contemporary technology makes it necessary to take full advantage of resources and facilities to succeed in the global market (Issamar et al. 2019).

The implementation of these tools arises from the need of a company in the Peruvian metallurgical sector to increase the availability of a machine that supplies semi-finished products to one of its main production lines. Specifically, it seeks to determine the influence that the implementation of lean manufacturing tools such as the single minute exchange of die (SMED), the 5s and Kaizen can have on the availability of the Slitter machine of this company. This indicator hardly exceeds 60%, which negatively affects the weighted value of Overall Equipment Effectiveness (OEE). Values between 75% and 85% are considered "acceptable". However, to qualify as "good" in the market, the value of 85% must be exceeded, which is within the parameters of the "world class" category (Algara and Sierra, 2018). For this applied research, the goal is to increase availability up to 74%. Also, it is worth mentioning that it is possible to notice significant improvements after the first month of applying lean manufacturing tools, which makes this methodology quite attractive (Singh et al. 2018).

So, it can be said that the aim of this research is to increase the productivity of the Slitter machine of a metalworking company through the implementation of lean manufacturing tools with the aim of improving its availability. To achieve this, the following specific objectives are proposed:

- Implement Kaizen and 5s to reduce machine downtime for unscheduled stop reasons.
- Standardize and optimize critical activities using One Point Lessons (OLP) and fabrication manuals.
- Reduce the time to identify and solve problems at the time of a machine stop.
- Apply SMED to reduce setup time and the total time of a machine operating cycle.

2. Literature Review

The metalworking sector constitutes a part within the manufacturing industry that is dedicated to produce a great diversity of goods, including inputs and key components for some industries such as the automotive, aeronautics, energy sector or construction (Becerril et al., 2018). According to the Central Management of Economic Studies of the Central Reserve Bank of Peru, the Peruvian metalworking industry grew 2.5% in 2019 (Tineo, 2020). Faced with this growth and in addition to the strong competition of metals from Asia, national companies are forced to increase their productivity and improve their production processes in order to stay competitive (Miñan, 2019).

Productivity is understood to be the relationship between the production obtained from a production or service system and the resources used to carry out production. Therefore, to improve productivity within a company, the efficient use of all resources is essential. We can increase productivity by producing more using the same amount of resources (Prokopenko, 1989).

Below is the general formula for calculating productivity:

$$\text{Productivity}= \frac{\text{Output}}{\text{Input}}$$

Also, another important indicator is the Overall Equipment Effectiveness, a concept developed by Seiichi Nakajima. This formula measures production performance by integrating the following data: availability, performance efficiency and the rate of quality achieved in production. (Belohlavek, 2006).
The following formulas are used to calculate these data:

$$\text{OEE} = \text{Availability} * \text{Performance} * \text{Quality}$$
$$\text{Availability} = \frac{\text{Available operating time}}{\text{Total operating time}}$$
$$\text{Performance} = \frac{\text{Total output}}{\text{Potential output}}$$
$$\text{Quality} = \frac{\text{Quality production}}{\text{Total production}}$$

On the other hand, according to Nakajima (1988), the OEE indicator tries to identify losses that consume resources without adding value to the final product. For this reason, he defines OEE as a bottom-up approach that involves the entire workforce in order to eliminate the six great losses, which are the following:

- Equipment failures: Unexpected failures that prevent the equipment from producing.
- Set up and adjustments: The exchanges of tools or adjustments to start production on each machine.
- Minor stops: Machine stops caused by minor problems that affect the speed of the process.
- Reduced speed: Equipment speed below standard.
- Scrap and reprocessing: These losses occur when the product does not reach the required quality level.
- Losses due to start-ups: They occur when the equipment is not properly stabilized so that the first products do not meet the proper quality.

Finally, Nakajima (1989) believes that the most effective application of OEE is through joint process teams and with basic application of quality control tools such as Pareto and cause-effect diagrams. These applications can be an important element when measuring OEE.

Also, when talking about business competitiveness, it is inevitable to fail to mention lean manufacturing tools. This methodology is composed of a set of tools whose purpose is to help eliminate operations that do not add value to the product and processes. In addition, they reduce the waste generated to improve operations, fostering an environment of mutual respect with the worker (Tapia et al. 2017). According to Galgano (2004), the implementation of lean manufacturing in a company that uses traditional methods can increase productivity by 100%, reduce inventories and cycle times by up to 90%, reduce customer complaints by up to 50%, among other results. A key element within these tools is the standardization of processes. According to Mantilla and Sanchéz (2012) it is said that an operation is standardized when the input requirements, the process activities, the time in each activity and the outputs of the operation are known. These standards are essential to be able to understand the initial situation of the process, sustain continuous improvement and to measure the results. Some of the lean tools are: Kaizen, 5s, SMED, and VSM.

Kaizen philosophy was originated in Japan by Masaaki Imai and means progressive improvement. It involves all parts of a company and establishes a lifestyle that seeks to improve constantly (Masaaki., 1989). This philosophy is focused on people and the results generated by the effort of each one of them. Therefore, it focuses on processes, since, by improving them, better final results are guaranteed. Furthermore, Kaizen is based on a culture of total quality. Companies implement Kaizen to improve their productivity, seeking to maintain and improve over time (Elizondo, 2007).

When mentioning the total unit in a company, it is important to talk about the Deming Wheel. It highlights the importance that exists in the interaction of all the parts of a company such as research, design, production and sales. In order to satisfy the costumer with an adequate level of quality, it is important to follow the four stages that are detailed in the PDCA cycle (plan, do, check and act) that suggest a specific order of activities for continuous improvement (Massaki, 1989).

- Plan: At this stage, a study of the current situation is carried out, in which data is collected with the aim to improve a certain activity.
- Do: In this stage the plan that has been designed is executed and the necessary actions are taken to carry out the improvements. Usually, to correct possible errors, a pilot plan is carried out.
- Check: In this stage the execution of the plan is reviewed to verify if changes can be made to increase the effectiveness.
- Act: At this stage, the necessary corrections and modifications to the initial plan are made to seek the continuous improvement of the development of the processes.

When seeking to improve a process, it is important to develop the Kaizen philosophy, since it has generated a process-oriented way of thinking and recognizes the effort of individuals for improvement. For this, there are 5 steps that are known as the 5s:

- Seiri (organize): Mantain what is necessary and discard what is not necessary.
- Seiton (order): Put everything in a specific place so that they are ready to be used when required.
- Seiso (clean): Keep the work area clean.
- Seiketsu (standardize): Keep what has been achieved.
- Shitsuke (discipline): Work in a disciplined way.

On the other hand, SMED is also part of the wide range of lean manufacturing tools. The application of this methodology allows the reduction of times in which the operator initially configures the machine to start the production of a batch (setup), so it is feasible to apply it in machines that manufacture different types of products. According to Rieger (2011), the implementation of SMED reduces the setup time and improves productivity. However, the results of applying this methodology are not limited to shortening the setup time. Companies that adopt this methodology can obtain a competitive advantage by eliminating stocks and revolutionizing their basic production concepts (Shingo, 1993).

This methodology is applicable to different industries. According to Senny et al. (2021) it was possible to apply SMED in a drawing machine of a steel company, reducing the setup time by 5.86 minutes and increasing the effective capacity by 21% as a result of the reorganization of the setup process. In the automotive industry, it was applied to reduce the setup times of an Electron Beam Machine (EBM), managing to reduce the times by more than 50% (Martins et al., 2018). For the pharmaceutical industry, the methodology was applied in a packaging machine and the setup time was reduced by 30% (Karam et al., 2018).

Like any methodology, it requires to follow a series of stages for its correct implementation. Mainly, there are four stages that are summarized in this way. First, there is the preliminary stage in which the operation to be changed is studied. Next, the stage of separation of internal and external activities (an external activity is defined as one that can be carried out with the machine turned on). Then there is the stage of conversion of internal and external activities. Finally, there is the stage in which operating activities are standardized (Domínguez et al., 2020).

At last, the Value Stream Map tool is a simple but quite effective method to illustrate processes. This method was originated in the Toyota production system and has two phases. First, the current value stream is analyzed to determine if there is a bottleneck (waste) in the flow design. Second, a new flow is proposed in order to eliminate the bottleneck. Finally, it can be said that this method is widely used within the industry (Haefner, et al., 2014). However, it is important to mention that the results achieved with lean manufacturing tools such as SMED, Kaizen or VSM will only be sustainable over time through standardization (Sundar et al., 2014).

3. Methods

This applied research aims to generate knowledge with direct application in the productive sector. Furthermore, it solves practical problems using existing methods (Lozada, 2014). Likewise, it can be considered as a qualitative-quantitative study; the combination of these two types of approach has a fairly high synergy. The evidence from quantitative data can provide relationships that are not initially taken into account by the researcher and qualitative evidence helps to understand the reason underlying the data obtained quantitatively (Eisenhardt, 1991). Considering this mixed approach, we seek to determine the influence of the implementation of lean manufacturing in the availability of the Slitter machine of the metalworking company XYZ.

The methodology that this case study follows was divided into three phases: initial, immersion in field and validation of findings. This structure was considered in order to increase the reliability of the research due to the large number of sources available to collect information (Yin, 1981). Table 1 details the structure of the points that were considered in each of the aforementioned phases.

Table 1. Outline of the methodology

Approach	Mixed with case study strategy		
Study subject	Slitter Machine		
Phase	Initial	Immersion in field	Validation of findings
Scope	Exploratory / descriptive	Descriptive / correlational	
Objectives	1) Identify problems related to maintenance, set up and the production process. 2) Identify the causes. 3) Identify possible solutions.	1) Select the best solutions. 2) Implement the selected solutions.	1) Validate the findings between the lean tools implemented and the availability indicator
Phase	Initial	Immersion in field	Validation of findings

Technique	Objective 1: Semi-structured interviews with managers, Objective 2: Review of machine documents and data, process observation and Ishikawa diagram. Objective 3: Review of the theoretical and contextual framework.	Objective 1: Ranking of factors, documentary review of studies on similar machines, interviews with operators and production and maintenance supervisors and Gantt chart. Objective 2: Tutorials, One Point Lessons (OPL), Visual Aids, and Problem-Solving Matrices Objective 3: Training.	Objective 1: Statistical validation of the hypothesis, in-depth interviews to validate the findings, compare the results with those of similar machines.
Analysis unit	Objective 1: General Manager. Objective 2: Plant Manager.	Objective 1: Plant supervisors. Objective 2: Operators.	Objective 1: Academic experts

4. Data Collection

To carry out an analysis of the indicators of the key processes of the XYZ Company, it is important to know the order of activities within the production chain. For this, Figure 1 shows the diagram that details the supply and production process of coils and strips. As can be seen in the block diagram, the processes of the Slitter and the Tube Forming Machine are the only ones where a product transformation is carried out, so they are considered key. To monitor its results, the company is guided by Overall Equipment Effectiveness (OEE), which measures production performance considering equipment availability, performance efficiency and quality (Belohlavek, 2006).

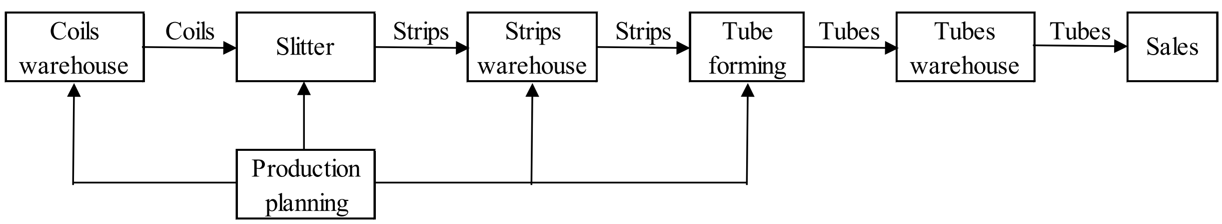

Figure 1. Coil and strip supply and production process

The organization seeks the constant improvement of the OEE, since it is commonly used in the sector to measure the competitiveness of companies. Therefore, increasing it is key so that the company under study can expand into new international markets. Currently, the indicator that negatively affects the OEE of the Slitter machine is the availability. Figure 2 shows the availability of the Slitter machine from August 2020 to August 2021. As can be seen, the availability hardly exceeds the value of 60%, which is considered unacceptable according to international parameters.

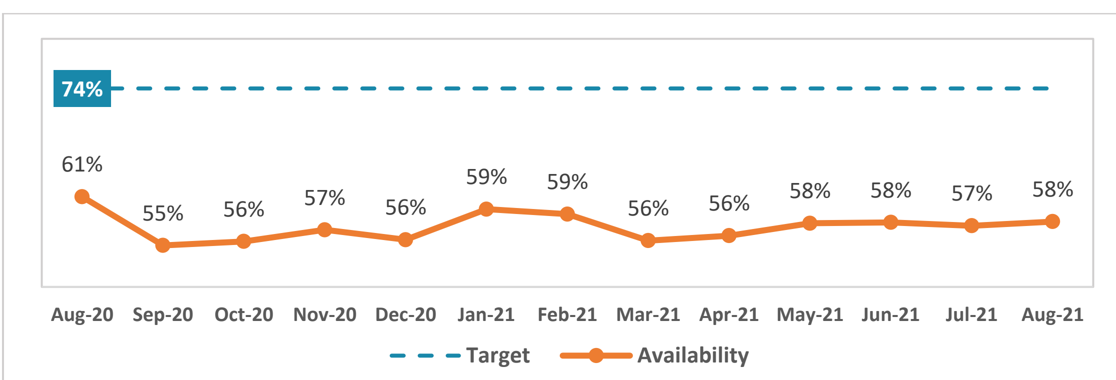

Figure 2. Slitter availability indicator

The Slitter consists of a continuous semi-automatic process that, through a series of blades located on a roller, cuts steel sheets according to the width that is required. The raw material for its manufacture is steel, which is acquired in the form of a coil, and cut according to the characteristics associated with the development of the type of tube to be manufactured.

The coil cutting process requires two operators: the lead operator and the assistant. The first one is in charge of assembling the cutting head, in which the blades that determine the number of strips to be cut are located. On the other hand, the second one is in charge of the installation of the steel coil (raw material of the process), the calibration of the tension elements and the assembly of the small heads. Likewise, once the cutting process is finished, both operators tie the different strips together. This procedure consists of placing straps around the strips so that they can be safely taken to the warehouse.
The production process is divided into 4 stages, which are detailed below:

1. Heads assembly: stage where the setup and calibration of the cutting head and the small heads are carried out. It is the most critical part of the process, as it requires great precision for finished products to meet quality standards.
2. Coil assembly: the steel coil to be cut is mounted on an unwinding roll with the help of a bridge crane. Likewise, the tension elements are calibrated in order to ensure the correct unwinding of the coil. It is worth mentioning that the coils weigh is between 6 and 14 tons, and it is extremely important to ensure that they meet the quality parameters required for the process.
3. Coil cutting: stage where the manufacture of the strips begins according to the production plan.
4. Strapping: once the entire length of the coil has been cut, the product (strips) is strapped. It is important to mention that the strips were wound around a head during the process. Finally, the strips are disassembled from the head and taken to their respective storage areas with the help of a bridge crane.

Table 2 shows the classification and times of each of these activities. It should be noted that the internal ones refer to the activities carried out with the machine stopped, and the external ones, to those carried out with the machine running.

Table 2. Internal and external activities

Activity	Time (min)	Type
Heads assembly (setup)	50	Internal
Coil assembly	9	Internal
Coil cutting	29	External
Strapping	16	Internal

On the other hand, it is important to mention that the Slitter can be configured in several different ways in order to take advantage of all the development of the coils and meet the quality requirements of the company. Currently, 9 types of strips are produced, which are called semi-elaborated products to be used in another process. Consequently, for each format change, the setup has to be changed and the machine calibrated again.

The assembly and disassembly procedure, or better known as setup, represents a significant fraction of machine downtime per production. Mainly, it consists of changing the blades, spacers and some additional parts of the machine. For this, there are fairly basic instructions and plans, in which the assembly and disassembly procedures are detailed. Figure 3 shows a Value Stream Map that details the times of each activity of the process.

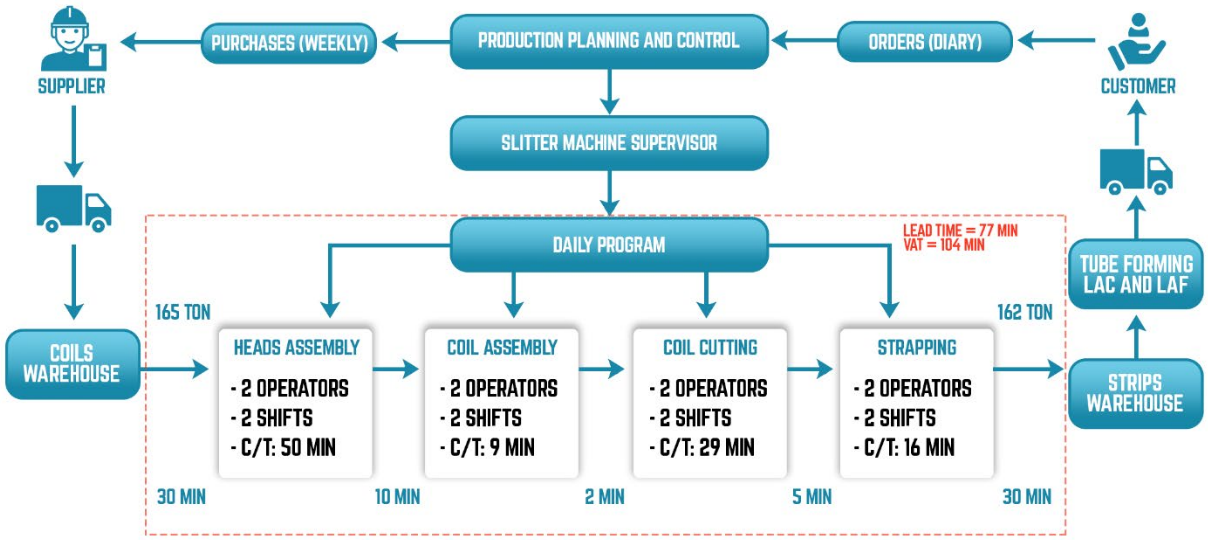

Figure 3. Current Value Stream Map

With the situation of the Slitter machine already detailed, it is important to mention that the availability of this machine is affected by unscheduled machine stops. These stops can be classified into four large groups: production, warehouse, maintenance and planning. Also, machine stops are generated due to setup procedures, which involve activities related to the preparation of the machine for the production process (setup change hours). Below, Table 3 and Figure 4 presents the detail of the machine stop hours between the months of August 2020 and August 2021. The data correspond to the monthly average in each item during the mentioned period.

Table 3. Detail of machine stops

Detail	Average
Scheduled hours	662.06
Scheduled stop hours	144.46
Available hours	517.6
Heads assembly hours (setup)	101.84
Coil assembly hours	35.6
Unscheduled stop hours	89.53

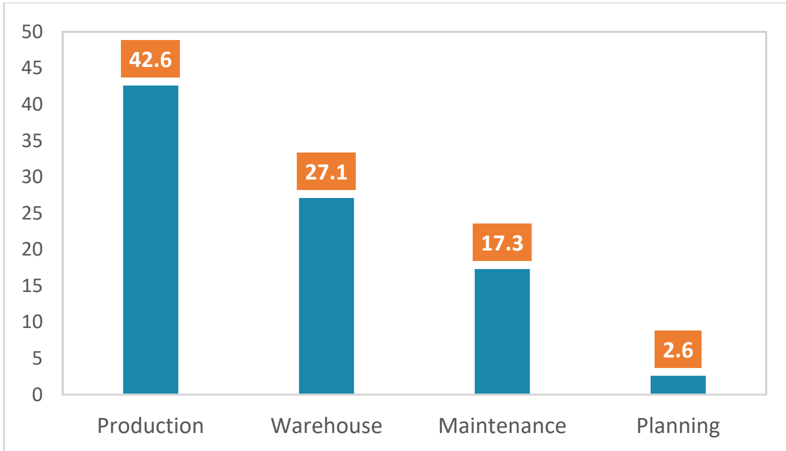

Figure 4. Detail of unscheduled machine stop hours

5. Results and Discussion

5.1 Numerical Results

After the improvements implemented, availability was increased by 95.73 hours per month (Table 4), which constitutes a significant increase. Between August 2020 and August 2021 there was an average availability of 57.29%; and now, after the improvements, it has been possible to reach 74.65%.

Table 4. Results in terms of time

Monthly results		
Detail	Initial situation	Final situation
Heads assembly hours (setup)	101.84	85.55
Coil assembly hours	35.6	35.6
Coil cutting hours	187.17	167.8
Strapping hours	103.46	64.67
Unscheduled stop hours		
Micro stops hours	18.74	4.31
Order and cleanliness	9.37	2.53
Total	456.18	360.46
Hours of difference	95.73	

5.2 Graphical Results

As can be seen in Figure 5, the activity times were reduced by 17 minutes per operating cycle. The activity of heads assembly had a reduction of 8 minutes, the cutting of coils was reduced in 3 minutes, and the strapping, in 6 minutes. Consequently, the value-added time (VAT) went from 104 to 87 minutes.

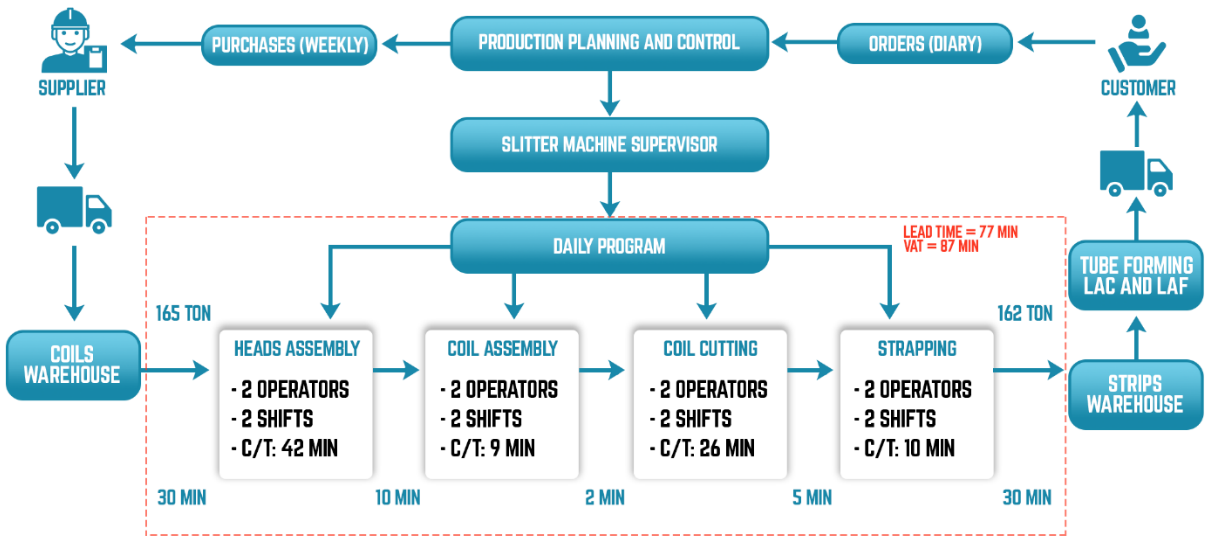

Figure 5. Final Value Stream Map

5.3 Proposed Improvements

Regarding the head assembly process, it can be said that the tool search activity had a representation of 3 minutes on the total time. For this reason, the 5s methodology was applied, with the aim of eliminating this type of waste. The locations of the tools were standardized, and the frequencies of use were determined to assign them a specific place with the objective that the operators did not waste time searching for them. The 5s methodology consists of five steps: organize, order, clean, standardize and maintain. First, the identification of all the work tools used in the Slitter machine was carried out. With this, we move on to the second and third steps, where the frequencies of use and conditions were determined. Consequently, tools that were out of use and in poor condition were removed. Next, a specific place was established for each tool, taking into account its frequency of use and functionality. Finally, a document was prepared to show the details of the location, the frequency of use and the usefulness of each of the tools. In addition, to maintain the standard, the document was published on one of the blackboards next to the machine.

On the other hand, the activity of assembling wooden slats, belonging to the process of heads assembly, was not optimized. The operator took a long time to make the holes for the metal bases, because he did not have the appropriate tools. For this reason, a drill and a ½-inch wood bit were purchased, and a new method was defined with which it was possible to reduce the time by 9 minutes. Likewise, this internal activity was transferred to the coil cutting process (external), since the assistant operator had 21 minutes of dead time. In addition, it was determined that the assistant operator should be in charge of managing the scrap (process waste), since the reorganization of activities increased his dead time during the head assembly process. Also, an instruction manual was developed to standardize this procedure.

Regarding the strapping activity, it can be said that it was not optimized, since the process was quite long and both operators had dead times that represented 12.5 minutes. For this reason, a new strapping method was defined, in which the operators work together. As a result, the total activity time was reduced by 6 minutes, dead times were significantly reduced and it was possible to redistribute the loads of the operators with greater equity.

On the other hand, the causes of unscheduled stops for production reasons were also attacked. In this area, the micro stops due to failure in the scrap accumulator, the removal of scrap and the order and cleanliness of the work area stand out. For its solution, One Point Lessons (OPL) formats were implemented with the aim of standardizing activities and reducing the chances of any inconvenience during production. It is worth mentioning that this type of solution, belonging to the Kaizen methodology, is commonly used to detail the procedure of simple and brief activities.

The micro stops for failures in the scrap accumulation process represented approximately 1.5 minutes for each coil cutting process. The causes were two: the scrap accumulator reaches its maximum capacity and stops accumulating or the scrap leaves the accumulator guide. Consequently, the line had to be stopped for the main operator to fix the problem. To solve this, an OPL was implemented to ensure the correct functioning. Likewise, a formula was developed to determine if it is necessary to remove the scrap before starting a new cutting process, in order to avoid stops due to scrap removal reasons during production. With this, it was possible to reduce machine downtime due to this type of problem by 77%.

Finally, the order and cleanliness of the work area was another of the unscheduled stops for production reasons that had a high representation. Therefore, within the heads assembly and coil cutting activities, 13 and 12 minutes respectively were included to perform this task. To standardize order and cleanliness, an OPL was implemented (images were included to standardize the conditions in which the work area must be found). Aspects such as cleaning process waste such as cardboards, straps, roll paper, metallic elements, wooden planks and steel dust are the most critical points, because they sometimes hinder the mobility of personnel under safe conditions. Also, it is important to note that the 5s were applied for the order of the tools (previously explained). With these improvements, it was possible to reduce this type of stops by 73%.

5.4 Validation

To validate the hypothesis, the upper tail test was performed for the statistical operator of the population mean with a known standard deviation (σ). For this, the number of samples n = 48 was used, which complies with being greater than 30, therefore it is considered adequate (Anderson et al., 2008). The steps for the calculation and the results obtained are detailed below.

Hypothesis: The implementation of lean manufacturing tools in the Slitter machine will increase its availability.
H_0: The implementation of lean tools will allow an increase in the availability of the slitter machine ≤ 74%
H_1: The implementation of lean tools will allow an increase in availability of the slitter machine> 74%

Confidence level = 95%
$\alpha = 0.05$
$\bar{x} = 0.7465$
$\mu_0 = 0.74$
$n = 48$
$\sigma = 0.0172$

Calculation of the Z test statistic:

$$Z = \frac{0.7465-0.74}{\frac{0.0172}{\sqrt{48}}} = 2.61$$

Calculation of p-value:
P (Z>2.61) = 1-0.9955 = 0.0045

Now, the rule for rejection using the p-value is used, which indicates that H0 is rejected if the p-value ≤ α (Batanero, 2001). For this research, with the data presented, a p-value = 0.0045 was obtained, which means that the probability that $\bar{x} = 0.74$ or less is obtained, if the null hypothesis is true, considered as equality, is 0.0045. Therefore, since 0.0045 is less than $\alpha = 0.05$, H_0 is rejected. In this way, it is concluded with a significance level of 0.05, that sufficient statistical evidence was found to reject the null hypothesis and, consequently, the alternative hypothesis H_1 is validated.

6. Conclusion

The increases of 17.36% in the availability and 10.37% in the productivity of the Slitter machine show that it is not necessary to make large investments in the latest technology to improve the competitiveness of companies. What really matters is to know the processes accurately and have detailed information about them. With this, problems can be identified and solved through the application of lean manufacturing tools.

According to data from the Slitter machine, setup time represented 27% of the hours available for production; and unscheduled stops, 17%. From this, it was concluded that the activities involved in the setup needed to be reorganized and standardized. Likewise, it was concluded that it was also necessary to train operators in order to avoid unscheduled stops. For these reasons, it was determined that SMED, Kaizen and 5's were the most appropriate tools to mitigate these problems.

It was shown that with the application of SMED, the project's base tool, machine setup times can be considerably reduced and activities that do not add value can be eliminated. In the present applied research, setup times and operation cycle times were reduced by 16% and 16.35% respectively. First, the process activities were classified as internal or external. Then, a time study was made to determine how long each activity takes to be finished and to identify operations that are performed inefficiently or that do not add value. With this, the process was reorganized in order to make it more efficient by increasing external activities and reducing internal ones.

On the other hand, the implementation of Kaizen and 5s was crucial in reducing machine downtime due to unscheduled stops. The development of One Point Lessons (OPL) and manufacturing instructions were helpful in reducing micro stop time, generating easy to understand visual aids for operators, identifying problems, and optimizing and standardizing activities. In the same way, the implementation of the 5s was useful to reduce the stop hours due to order and cleanliness.

In addition, it´s important to mention that the hypothesis was statistically verified with a p-value = 0.0045 which, being less than $\alpha = 0.05$, confirms that the implementation of lean tools will allow an increase in availability of the slitter machine greater than 74%.

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