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Application of Lean Techniques to Reduce Preparation Times: Case Study of a Peruvian Plastic Company

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Abstract

This article examines the problem of an increase in product returns for a company that produces plastic films for flexible packaging. Among the factors that have resulted in the increase of returned products are defects in the films caused by the poor manipulation of materials and, above all, the hard point in the coils caused by excessive extruder preparation time, causing the extrusion head to overheat as well as uneven extrusion. Extrusion is a key process in the production of plastic materials as it transforms polypropylene and additives into plastic sheets. The delay in the preparation time caused by machine operators leads to the overheating of the extrusion head and, therefore, defective products that are ultimately returned to the company by customers. In order to confront this problem, a proposal was developed using the SMED tool of Lean Manufacturing in order to reduce the preparation time of the extruder and to increase the productivity of the company. For the validation of the proposal, we simulated the system to determine the resulting reduction in extruder preparation time.

Keywords: productivity, extrusion, preparation time, SMED, lean manufacturing, simulation.

INTRODUCTION

Currently, the plastic industry is heavily automated due to the complexity of its processes and the goal of standardizing the production of plastic products. The company examined in this study is dedicated specifically to the production of plastic films for flexible packaging, which are often used in the wrappers of snacks, cookies, ice cream and different food products. The process of obtaining this material occurs in several stages, including extrusion where the problems that lead to defects in the films most often occur.

The company has noted that, over the last twelve months, the amount of products that have been returned by customers has increased and exceeds the limit established by the product return policy of the company.

These products were returned because they have physical defects that were detected by the client when the reels of plastic film were deployed for printing. In the current study, the percentage of defective products that originated in the extrusion process were analyzed. It was found that, when preparing the extruder machine for create a new unit of plastic film, the operators conduct activities that need to occur within a certain time frame specified by the manufacturer that is not being met. When the actual time spent exceeds the recommended time, this causes the main head of the machine to increase in temperature even though no work is being performed, causing the subsequent film roll to contain defects in the hard point among other areas.

To mitigate this problem, the SMED tool was developed with the aim of reducing the time needed to execute the different stages of the process. The proposal was validated by simulating the modified process.

Although technical characteristics indicate that the preparation time should not exceed 100 minutes for this particular machine, this may not always be feasible and it is necessary to take into account the external factors that affect the preparation time variable, as was done in this study.

LITERATURE REVIEW

In recent academic articles, the implementation of an improvement to the production process within an organization uses more than just a flow chart or Value Stream Map. The trend in these articles has been the use of Lean Manufacturing tools that more focused on solving specific problems which may affect the whole process or a particular part. These problems can range from operative to environmental in nature [1].

For the company examined in this study, the most important process that occurs is extrusion, a mechanical industrial process where the polymer is molded through its continuous flow under pressure and forced to pass through the mold, thus forming the film [2].

In different investigations, the application of Lean Manufacturing techniques has had positive results on the production processes of companies; improving the efficiency, productivity and quality of their production processes. The Lean Manufacturing philosophy calls for the identification of actions or activities that do not add value to the production process so that they can be either reduced or eliminated. This reduces the production cost and results in improved productivity, better product quality and shorter product delivery time. In addition, this methodology can tackle different problems that occur during the production process such as overproduction, reprocessing, excess inventory, movements, unnecessary transport, defective products and delays [3].

Lean Manufacturing means eliminating production waste from different industries. Regarding this, Shah and Ward stated the following [4]:

> "It is most frequently associated with the elimination of the seven important wastes called molt in Japanese. The seven original wastes (muda) are overproduction, production ahead of demand, waiting (waiting for the next stage of production), unnecessary transportation, or incorrect processing, excessive inventory, movement or unnecessary movement, and defects and reworking ." (Shah and Ward 2003)

Zahraee expressed the following on lean manufacturing [5]:

> "Lean Manufacturing (LM) is a business strategy that was developed in Japan. The main contribution of lean manufacturing is the identification and elimination of waste. Companies apply LM to maintain their competitiveness against their competitors by improving the productivity of the manufacturing system and improving the quality of the product. The objective of this work is to apply one of the most significant lean production techniques called Value Stream Mapping (VSM) to improve the production line of a company that produces several components for the vehicle assembly line, decreasing the waste activities and not valued." (Zahraee 2014)

The Lean Manufacturing tool that was used in this study to reduce extruder preparation time is the SMED. SMED is the English acronym of Single Minute Exchange of Die (Change of series in a digit of minute) and is a tool that helps companies reduce preparation times by streamlining preparation activities so that as many as possible are performed while the machine is on. The tool is based on reorganizing the activities (external and internal) of a certain process and performing some in parallel so that they require the shortest possible time. It is a very effective method for reducing machine configuration and increasing productivity [6]. The concept behind SMED asserts that all steps and preparation procedures should last less than 10 minutes and should ensure that the largest number of internal activities are converted into external activities, meaning that as many activities as possible are carried out while the machine is on and in preparation. The benefits of applying SMED are lowering costs and achieving greater time flexibility [7]. Figure 1 shows the different phases involved in the development of the SMED tool within an organization.

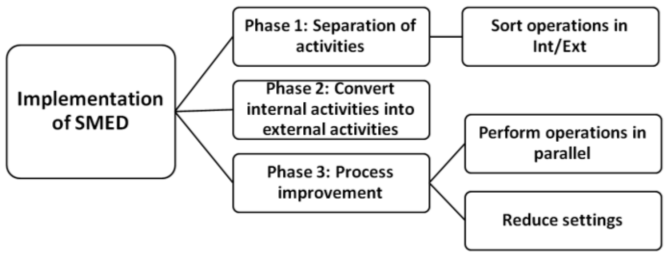

Figure 1: SMED process
Source: self made

The tool seeks to standardize and reduce activities that do not add value to the machine preparation process by changing production in a given manufacturing company. Shingo (1985) separated the preparation activities of such change into two parts [8]:

- Internal activities: Those activities that can be performed when the machine is stopped and is not producing.
- External activities: Those activities that can be performed when the machine is running, that is, with an idle time equal to zero.

Below is a detailed description of each phase of the SMED tool [9]:

In the preliminary phase, the elements are identified in detail. Then, in the first phase, they are separated and classified into internal and external activities. It is necessary to consider the activity diagram of the preparation process for the machine that will be targeted by the SMED tool during this time.

The second phase consists of converting most of the internal activities into external ones, taking into account that all activities for the preparation of tools and devices or the search for materials must be external in order to take advantage of downtime.

In the third and final phase, with separate preparation activities, it is necessary to look for internal activities that can be carried out in parallel in order to reduce the overall preparation time. If this is achieved, all these applied actions must be perfected, taking into account the considerations and theory of the tool as well as the technology needed to eliminate some transfer activities.

In practice, companies also apply reengineering, process improvement, TPM (Total Productive Maintenance) or apply a Lean Sig Sigma strategy in order to reduce preparation, maintenance or blocking times. It is necessary to focus on

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each of the tools aimed at reducing production time while considering also the maturity of the company so that the changes are beneficial and the results achieve their objectives [10].

CASE STUDY

The current study focuses on a company that produces plastic films for flexible packaging. Its production plant is located in Lima, Peru.

The plastic film production process begins with the combination of polypropylene and additives during the extrusion process until the film is obtained and later molded, laminated and stretched. When the film is ready, it is sealed and rolled. The coils are cut and stored until the order is delivered.

Recently, the company in question has had a problem with product returns. In the last 12 months, the percentage of returned products has been around 4% despite the fact that the company has a maximum refund policy of 2% based on the investment they have made in the automation of production processes and quality control. Table 1 shows the quantities (in kilograms) and the percentage of products returned per month.

Table 1: Number of returns in the last 12 months

PRODUCT RETURNS			
MONTH	**QUANTITY (Kg)**	**SALES (Kg)**	**%**
apr-16	199525	8070130	2%
may-16	201031	5943830	3%
jun-16	201321	5610440	4%
jul-16	200662	6317800	3%
aug-16	201458	7075330	3%
sep-16	198722	6885480	3%
oct-16	197923	6049020	3%
nov-16	199565	5094010	4%
dec-16	201998	5000950	4%
jan-17	202732	5074770	4%
feb-17	205234	5714660	4%
mar-17	206222	6394680	3%
AVERAGE	**201366**	**6102591**	**4%**

Source: Company

Figure 2 shows the increase in returns over the last 12 months.

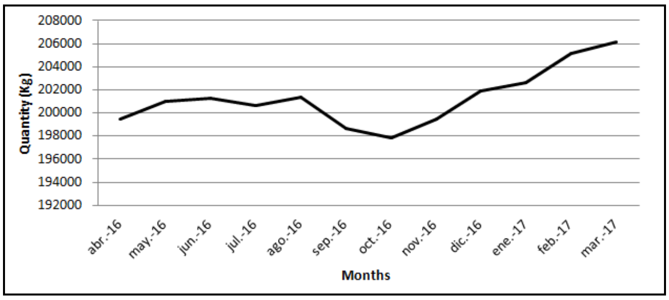

Figure 2: Returns of products
Source: self made

For twelve months, the number of plastic films returned by customers has been increasing (Figure 2) due to several different factors that will be analyzed later in this investigation.

The average rate of product returns over the last twelve months has been 4% of the total material sold. The return policy of the company specifies that the percentage of returns of products should not exceed 2% of total sales, since two of its strategic processes are quality assurance and quality control. These processes are meant to ensure that the company's products meet and exceed the quality and safety specifications required by the client. In addition, statistics indicate that, for the plastic products manufacturing sector, the average return rate is 2%, since most of the process is automated. Based on this analysis, it can be concluded that the problem of product returns is representative of a larger problem and it is necessary to analyze its causes in order to decrease this percentage as it is affecting the company's client base and bottomline.

The Planning and Production Control area names the products returned by the customer using PNC (Non-Conforming Products), a type of nomenclature used for records and management reports. The PNC, upon arrival, are received and deposited in the finished product warehouse of the company.

The company made a summary table (Table 2) relating to the main defects present in the products returned. These statistics include information of all the films in general terms, the process where the defects occur and the responsibility for the error (handling or machine).

Table 2: PNC Defects

DEFECTS OF PNC (april 2016 - march 2017)			
Rótulos de fila	%	Error	Process
CORRUGATED	0,09%	MACHINE	PREPARATION
APPEARANCE	0,99%	HANDLING	TRANSPORT
WRINKLES	4,05%	HANDLING	MOLDING
CARBONES	0,83%	MACHINE	PREPARATION
SPARKS	1,37%	MACHINE	EXTRUSION
COF OUT OF SPECIFICATIONS	1,78%	HANDLING	PREPARATION
DISCALIBRE	3,42%	MACHINE	EXTRUSION
DETACHMENT	0,76%	HANDLING	ROLLED
SPLICES	0,79%	HANDLING	EXTRUSION
STRETCH MARKS	2,63%	HANDLING	TRANSPORT
STRIPES	8,82%	HANDLING	TRANSPORT
SPOTS	11,25%	HANDLING	TRANSPORT
MARKS	8,40%	HANDLING	TRANSPORT
POROSITY	3,15%	MACHINE	EXTRUSION
BAD LABELING	6,82%	HANDLING	EXTRUSION
RASPONS	1,36%	HANDLINGN	TRANSPORT
STREAK	4,48%	HANDLING	TRANSPORT
OUTGOING	0,62%	MACHINE	STRETCHING
DESTINATION ERROR	11,84%	HANDLING	SHIPMENT
TTONALITY	1,50%	MACHINE	PREPARATION
TONE	0,61%	HANDLING	PREPARATION
TTREATMENT	1,60%	HANDLING	PREPARATION
BRAIDS	2,00%	MACHINE	MOLDING
HARD POINT	20,85%	MACHINE	EXTRUSION
TOTAL	100,00%		

Source: Company

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It is necessary to prioritize the types of defects found in the products returned over the last twelve months in order to know where to focus the SMED tool in order to mitigate the occurrence of these particular defects. In order to accomplish this, the Pareto tool will be used with the information provided by the company.

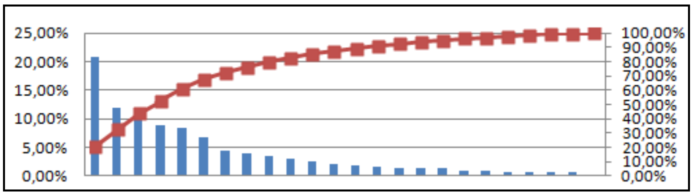


Figure 3: Pareto diagram of the main defects of the returned products

Source: self made

From the Pareto diagram we concluded that if defects of hard point, spots, marks and stripes were eliminated, it would resolve 80% of the problem. Thus, the improvement of the production process should be focused on the areas where these problems originate.

Main causes:

- Hard point: Defect occurs during the extrusion process.

All the heaters of the extruder are turned on until they reach the optimum temperature for working with plastic films. This process is done over continuous periods until the extrusion head regularly pumps the resin or until the molten resin leaves the head in a consistent manner. When a production change is made, it is necessary to turn off the machine to prepare to perform the process again. This process should last 100 minutes according to machine specifications. Figure 4 shows the flow of the production change process of the extruder machine.

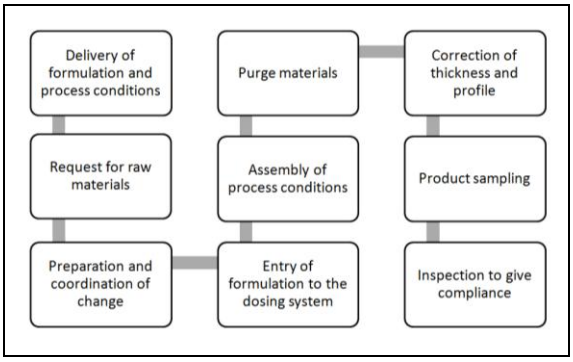


Figure 4: Flow chart of the setup process of the extruder

Source: Company

The temperature of the head should be as high as the temperature of the resin as this results in a well-extruded and complete film. However, when the operators delay more than the time indicated, the temperature of the head does not reach the temperature of the fluid (Figure 5) at the time of ignition. This causes the creation of a hard point in the plastic films, causing a certain area of the film to have a greater mass than other parts of the film and resulting in complications during printing.

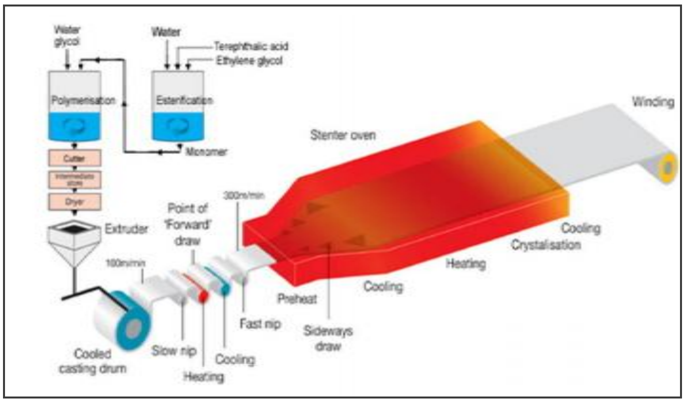


Figure 5: Extrusion machine head

Source: Company

Therefore, the company recorded the preparation time spent by operators during the process of production change. This is shown in Table 3.

Table 3: Random sampling of extruder preparation time

Experiments	Preparation time (min)
Test 1	139
Test 2	139
Test 3	139
Test 4	138
Test 5	140
Test 6	139
Test 7	138
Test 8	139
Test 9	139
Test 10	140
Test 11	139
Test 12	138
AVERAGE	**139**

Source: Company

The recording of the preparation time was performed by the company and each time recorded represented the average time that workers spent in preparing the extruder for the change of production per month until February 2017. The test was done with a confidence level of 95.45% and a margin of error of ± 5% using sampling.

Table 3 indicates that the average time that operators spent was 112 minutes, when it should be 100 minutes. This causes PNC to develop hard point failures and faults such as spots, scratches and marks.

Diagnostic

Figure 6 shows the tree diagram of the causes of the main problems of the company based on the previous analysis.

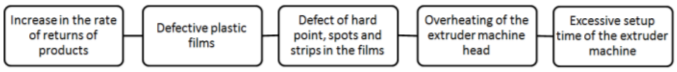


Figure 6: Diagnostic of the problem

Source: self made

The SMED tool would allow the company, after its development, to reduce the configuration time of the extruder machine when converting internal activities into external ones and would also allow the company to realize some activities in parallel given the previous implementation of the necessary technology.

The engineering methodology that includes SMED is Lean Manufacturing. Therefore, in this project, the proposal was developed based on this methodology and took into account the considerations and stages of implementation. Lean Manufacturing was chosen because it is a tool that focuses on mitigating the seven wastes of production processes: overproduction, delays, unnecessary transportation, reprocessing, excessive inventory, unnecessary movements and production defects. Figure 6 shows that three of the seven wastes were mitigated using Lean Manufacturing.

Methods

As demonstrated above, the main defect found in products that were returned was the presence of a hard point caused by the overheating of the extruder head due to delays in the preparation process. The company recorded the average preparation time and it was evident that they were well above the preparation time specified by the manufacturer. Therefore, the SMED tool must be developed in the area of extrusion to improve the preparation process and reduce preparation time in order to avoid hard point defects.

Sensitization

Lean Manufacturing training includes theory and procedures for the application of the SMED tool in an organization. At this stage of the process, each operator will be sensitized, especially the extrusion operators who are the ones involved in the preparation of the extruder machines. They must be made aware of the upcoming changes in order to achieve a reduction in the preparation time for production change and to adapt to performing the proposed activities based on the development of the tool in the work area.

Activity planning

According to the implementation process of the SMED tool in the case of this company, the process would last four months (from March to the end of June) during which the three stages of the tool would be developed. This effort would be coordinated and executed by "the Lean team." Figure 7 shows the members of the Lean team in charge of the SMED tool.

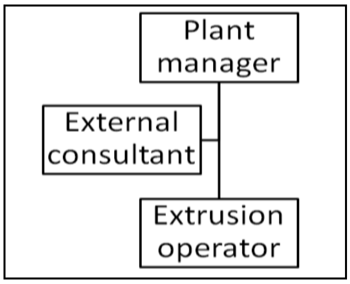
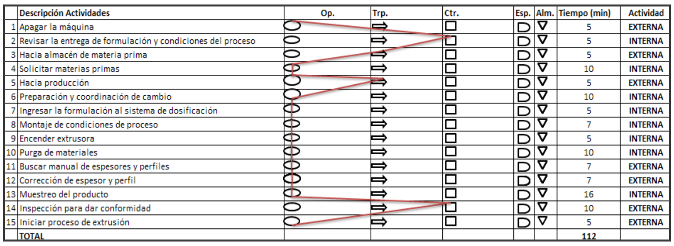


Figure 7: Members of the Lean team
Source: self made

Preliminary phase: identification of internal and external activities

Before starting to develop the tool itself, all the activities of the production change preparation process of the extruder machine must be identified. These activities are shown in Figure 8 along with their respective times and their classification as either internal or external activities.



	Descripción Actividades	Op.	Trp.	Ctr.	Esp.	Alm.	Tiempo (min)	Actividad
1	Apagar la máquina	◯	⇨	□	D	▽	5	EXTERNA
2	Revisar la entrega de formulación y condiciones del proceso	◯	⇨	□	D	▽	5	INTERNA
3	Hacia almacén de materia prima	◯	⇨	□	D	▽	5	EXTERNA
4	Solicitar materias primas	◯	⇨	□	D	▽	10	INTERNA
5	Hacia producción	◯	⇨	□	D	▽	5	EXTERNA
6	Preparación y coordinación de cambio	◯	⇨	□	D	▽	10	INTERNA
7	Ingresar la formulación al sistema de dosificación	◯	⇨	□	D	▽	5	INTERNA
8	Montaje de condiciones de proceso	◯	⇨	□	D	▽	7	INTERNA
9	Encender extrusora	◯	⇨	□	D	▽	5	INTERNA
10	Purga de materiales	◯	⇨	□	D	▽	10	INTERNA
11	Buscar manual de espesores y perfiles	◯	⇨	□	D	▽	7	EXTERNA
12	Corrección de espesor y perfil	◯	⇨	□	D	▽	7	EXTERNA
13	Muestreo del producto	◯	⇨	□	D	▽	16	INTERNA
14	Inspección para dar conformidad	◯	⇨	□	D	▽	10	EXTERNA
15	Iniciar proceso de extrusión	◯	⇨	□	D	▽	5	EXTERNA
	TOTAL						112	

Figure 8: Internal and external activities of production change

Source: self made

First phase: Separation of internal and external activities

All parts of work preparation do not need to be performed when the machine is stopped. However, this occurs.

Internal activities are those that are carried out when the machine is stopped and external activities are those that can be performed when the machine is running.

In this context, the internal activities of the production change process are the following:

- Review of the delivery of raw materials and process conditions
- Request raw materials
- Preparation and coordination of change
- Add the raw materials to the dosage system
- Assembly of process conditions
- Turn on the extruder machine
- Material purge
- Product sampling

The external activities of the process are the following:

- Turn off the extruder
- Go to the raw material warehouse
- Go to the production area
- Search thickness and profiles manual
- Correction of thickness and profile
- Inspection to give compliance
- Start the extrusion process

Table 4 shows the number of minutes for each type of activity after separation.

Table 4: Time of internal and external activities

ACTIVITIES	CURRENT TIME (min)	%
INTERNAL	83	74%
EXTERNAL	29	26%
TOTAL	112	100%

Source: self made

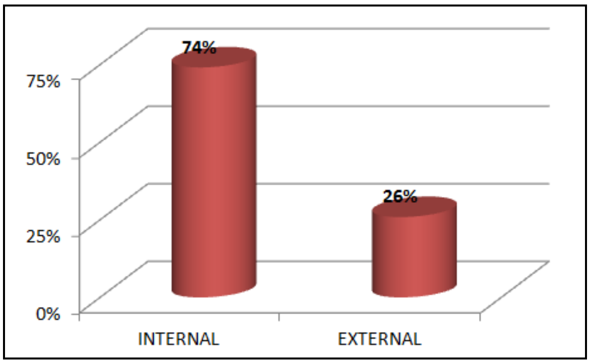


Figure 9: Bar chart of the time spent on internal and external activities before modifying activities

Source: self made

In Figure 9, it can be observed that the internal activities represent 74% of all of the activities of the machine preparation process. The objective of the SMED is to reduce the preparation time by converting internal activities into external activities and by carrying out parallel activities through the application of the Lean Manufacturing theory.

Second phase: Convert internal activities into external ones

The theory of the SMED tool asserts that all activity involving revision or work preparation must be done when the machine is on to save time. The company used this tool to convert internal activities into external activities. In addition, it is necessary to eliminate transfer activities or requests for tools or materials. This makes it necessary to implement other mechanisms that allow operators to communicate or place orders without having to leave the work area. These changes are shown in Figure 10.

	Descripción Actividades	Tiempo (min)	Actividad	Responsable	
1	Apagar la máquina	5	EXTERNA	Op. Extrusión	
2	Revisar la entrega de formulación y condiciones del proceso	5	INTERNA	Coord.Producción	EXTERNO
3	Hacia almacén de materia prima	5	EXTERNA	Coord.Producción	ELIMINA ACT.
4	Solicitar materias primas	10	INTERNA	Coord.Producción	ELIMINA ACT.
5	Hacia producción	5	EXTERNA	Coord.Producción	ELIMINA ACT.
6	Preparación y coordinación de cambio	10	INTERNA	Coord.Producción	EXTERNO
7	Ingresar la formulación al sistema de dosificación	5	INTERNA	Programador	
8	Montaje de condiciones de proceso	7	INTERNA	Programador	
9	Encender extrusora	5	INTERNA	Op. Extrusión	
10	Purga de materiales	10	INTERNA	Op. Extrusión	
11	Buscar manual de espesores y perfiles	7	EXTERNA	Op. Extrusión	ELIMINA ACT.
12	Corrección de espesor y perfil	7	EXTERNA	Programador	
13	Muestreo del producto	16	INTERNA	Programador	
14	Inspección para dar conformidad	10	EXTERNA	Coord.Producción	
15	Iniciar proceso de extrusión	5	EXTERNA	Op. Extrusión	
	TOTAL	112			

Figure 10: Change of machine configuration activities
Source: self made

According to the SMED tool, the activity of reviewing the delivery of the raw materials and conditions of the process along with the preparation and coordination of the change with the production coordinators must be carried out when the machine is in operation. For this reason, it is necessary to consider them as external while taking into account the perception of the operators that perform this action and the training that they must be given so they can perform the activities while the machine in motion.

The activities that involve going to other areas and requesting material were ignored as the implementation of internal intercoms was proposed in order to save time spent going to other areas and requesting material. The activity of searching for the manual to configure the thicknesses and profiles of the films was also disregarded. Table 5 shows the time of the internal and external activities after converting these internal activities to external ones and eliminating others.

Table 5: Time of internal and external activities proposed

ACTIVITIES	CURRENT TIME (min)	%
INTERNAL	58	68%
EXTERNAL	27	32%
TOTAL	85	100%

Source: self made

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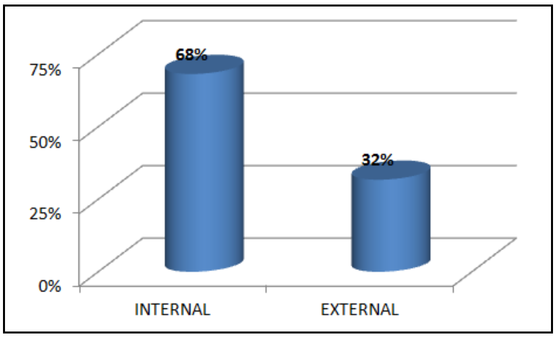

Figure 11: Bar chart of the time of internal and external activities proposed
Source: self made

In Figure 11, it can be seen that, after the conversion of internal activities into external activities and eliminating activities that do not add value, the percentage of internal activities was 68%, a 6% reduction compared to the company's current internal activities.

Third phase: Perfect internal activities

Parallel activities: After completing the second phase, the tool suggests looking for activities in the new activity diagram of Figure 12 that can be done in parallel in order to save time.

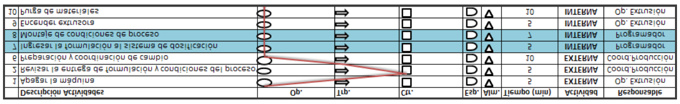

Figure 12: Parallel activities of the production change process

Source: self made

The activities of entering the raw materials into the dosing system and setting the process conditions are two activities of the preparation process that can be carried out in parallel with the support of the production coordinator. No increase in operating costs would be incurred for hiring new personnel due to the time gained following the completion of phase 2. When considering these activities in parallel, the longer calculation time is taken into account. In this case, both activities performed in parallel would take 7 minutes. Table 6 shows the time reduction resulting from performing some activities in parallel.

Table 6: Time of proposed activities

ACTIVITIES	CURRENT TIME (min)	%
INTERNAL	53	66%
EXTERNAL	27	34%
TOTAL	80	100%

Source: self made

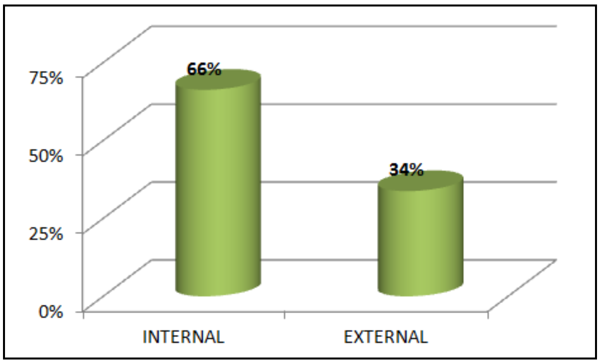

Figure 13: Bar chart of the proposed time of activities

Source: self made

Figure 13 shows that internal activities now represent 66% of the process of production change and external activities 34%. This indicates that the tool fulfilled its main objective of converting internal activities into external ones in order to reduce preparation time due to configuration changes.

After the development of the SMED proposal, a 32 minute reduction in preparation time resulted (Table 7), a considerable reduction that would benefit the company. However, all considerations must be taken into account in order for the proposal to be considered feasible.

Table 7: Time reduction with SMED

ACTIVITIES	CURRENT TIME (min)	SMED TIME (min)	SAVING (min)
INTERNAL	83	53	30
EXTERNAL	29	27	2
TOTAL	112	80	32

Source: self made

Perfecting production aspects During the development of the SMED proposal, eliminating those activities that did not add value to the process and that consisted of going to other areas to place orders was proposed. This is feasible as long as the necessary technology is implemented so that the collaborator can communicate with with other work areas from their own work area, in this case the extrusion area.

Figure 14: Electrical intercoms

Source: self made

A company policy forbids the use of cell phones inside the production plant because they can fall and cause accidents with machinery. Thus, in order to be able to communicate between areas without having to leave the work area, the installation of intercoms, such as those shown in Figure 14, was proposed to allow operators to request certain materials. This system would allow the collaborator to stay in his work area and to communicate directly with the warehouse to ask for supplies necessary to the extrusion process. This proposal reinforces the development of the second phase of the SMED tool.

VALIDATION

In order to validate the aforementioned proposal in a technical manner, the state of the system after the proposal's implementation was simulated and compared to the present state. The data used to simulate the modified system came from the sampling of extruder preparation time carried out by the company. The environment of the problem was then analyzed to simulate alternative solutions. In this study, the software used to simulate was the Arena Simulator and Input Analyzer.

The main problem with the company's production process, as previously mentioned, is the delay of operators in preparing the extrusion machine to restart the production process. This causes the extrusion head to overheat and affects the quality of the subsequent film because it does not extrude the material at the same temperature. According to the sales area report, the highest percentage of returns due to product defects is due to this issue.

Description of the system

The process begins with reviewing the delivery of the raw materials and the conditions of the process. Next, the raw materials are requested from the warehouse. In the area of extrusion, the preparation and coordination of changes is performed in order to enter the necessary input into the machine and to carry out the assembly of other process conditions. When the extruder is turned on, the materials are purged. It is then necessary to go to the tool area to find the manual of thicknesses and profiles and then perform the corrections. Finally, a sample of the product is taken and inspected in order to start the extrusion process.

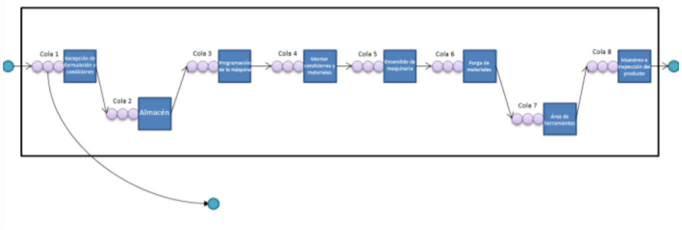

Figure 15: Graphic representation
Source: self made

Analysis of data

In order to simulate the effect of the proposal, the data (received from the company planning area) of all recorded extruder preparation activity times were analyzed with the help of the INPUT ANALYZER software in order to obtain the best distribution of each one.

- Reception time (TREC): Database where the time required for operators to receive all the information needed to start executing the production change is registered.
- Time of arrival at the warehouse (TELLalmacén): Database where the time that operators delay in going to the warehouse, requesting the required material and returning to the machine is registered.
- Time of programming of the machinery (TPRO): Database where the time that operators delay in indicating to the programmers the change of production and adjusting the changes is registered.
- Time to assemble materials (TMON): Database where the time it takes to assemble the materials (pellets) in the extruder machine for processing is recorded.
- Time to turn on the machinery (TENC): Database where the time that the machine is delayed in turning on in order to work with new material is registered.
- Material purge time (TPUR): Database where the time that the machine is delayed to perform a material purge is registered.
- Time to search for tools (THER): Database where the time that operators spend looking for tools and manuals to monitor the extrusion process is recorded.
- Sampling and inspection time (TINS): Database where the time that the operators spend on inspection is registered.

After entering the data of the recorded times into the Input Analyzer software, it produced the following distributions for all times:

- The most suitable distribution for the TREC variable is: UNIF (7.5, 12.5)
- The most suitable distribution for the TELL store variable is: 18.5 + ERLA (0.75, 2)
- The most suitable distribution for the TPRO variable is: UNIF (13.5, 17.5)
- The most suitable distribution for the TMON variable is: NORM (7.07, 0.814)
- The most suitable distribution for the TENC variable is: UNIF (3.5, 6.5)

- The most suitable distribution for the TPUR variable is: UNIF (7.5, 12.5)
- The most suitable distribution for the THER variable is: 11.5 + ERLA (0.6, 2)
- The most suitable distribution for the TINS variable is: UNIF (29.5, 33.5)

To simulate the SMED model, it is necessary to consider that, being a Lean tool, its application is *in situ* as it requires changes be made to the same facility. However, due to the time and workload of the company, it was not possible to carry out a pilot test to implement the methodology. Therefore, the execution of the SMED tool was simulated considering the company's constraints, the sampling times, the change of processes and the combination of activities to be carried out in parallel. In the second phase of the SMED model, it was determined that the transport and search times should not be taken into account for the simulation:

- Time of arrival at the warehouse: TELLalmacén (Consider time 0)

- Time to look for tools: THER (Consider time 0)

In addition, in the third phase, the tool considers that the activities of the programming (TPRO) and the material purge (TPUR) can be carried out simultaneously in the system. In order to show this, a "Decide Process" must be added to the Arena model since both will be executed at the same time. The programming code for this is the following:

(NR(Operator 2)<MR(Operator 2)).OR.(NR(Operator 3)<MR(Operator 2))

In the Arena software, NR means a busy resource and MR means the capacity of the resource. The code described means that, when one of the statements is true, at least one server is unoccupied to run the process. In this way, both activities can be carried out at the same time if resources (employees) are available.

Finally, in order to run the model, it is necessary to take into account the work schedule for each shift of the company. The shifts are divided into 8 hours each with a break time of 1 hour for workers. Figure 16 presents the simulation of the proposed model for extruder machine preparation made with the proposed modifications using the SMED tool.

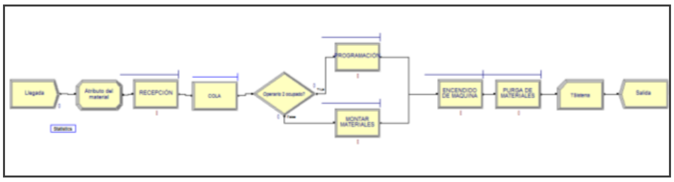

Figure 16: SMED simulation model in Arena

Source: Arena

RESULTS

After performing the simulation of the proposed SMED model with Arena, the results shown in Figure 17 were obtained. The model ran without any problem, meaning that no errors arose and it was feasible to make changes. In addition, the estimated preparation time for the machinery after the changes were made was 78.90 minutes, a value that is within the specified time limit, meaning that the extruder can be prepared without negatively affecting the production of plastic films. All the data were entered according to the distributions that were adjusted with the INPUT ANALYZER, meaning that there is a high level of confidence in the data proposed. Thus, the proposed methodology is considered operationally viable and the considerations of the model in question were taken into account along with the software, the restrictions of the company and the work schedule.

Unnamed Project — Replications: 10

Replication 1 — Start Time: 0,00 — Stop Time: 480,00 — Time Units: Minutes

Entity Detail Summary

Time

	NVA Time	Other Time	Total Time	Transfer Time	VA Time
Cliente	0.00	0.00	78.90	0.00	78.90
Total	0.00	0.00	78.90	0.00	78.90

Figure 17: Arena Report
Source: Arena

Before performing the analysis of the simulation, it is necessary to elaborate upon the changes that were made in order to simulate SMED's proposal.

The budget of the project included the purchase of intercoms and their installation within the work areas with the purpose of ordering materials from the workplace without having to physically go to the raw materials warehouse. This was done with the purpose of eliminating the Transfer activities during the preparation of the machinery. In addition, the purchase of mobile tool containers was included in the budget so the operator can leave the necessary tools and manuals for the preparation of the extruder next to the machine.

Some activities can become external (work while the machine is on) such as the receipt of the formulation and conditions for the production change, the activity of preparation and coordination with the programmers

In the simulation, after structuring the conditions and changes of the machinery preparation process (extruder) for the production change in the software, the overall preparation time was reduced to 78.90 minutes after the changes were made. The model ran without any problem and took into account the consideration of the sequence of the process activities. This means that the proposal is technically viable. In addition, the time estimated by the simulator when running the proposal model is within the range indicated by the technical specifications of the machine, meaning that there are no problems in the production related to preparation time after making the change.

The results of the model indicate that the preparation time of the extruder machine, when the changes with SMED were considered, is 78.9 minutes. The model of implementation of the tool indicates that the time is 80 minutes. The difference between the two figures is that the model yields more accurate data due to the precise distributions of the simulator.

Indicator

Based on the resources used to implement the SMED proposal in the company's production process, it was decided to measure the improvement with the indicator shown in Figure 18, which stipulates that a reduction of more than 30% in setup time is optimal. This was done with the purpose of not affecting the company economically. The results obtained by the simulation model indicated that the reduction obtained with the application of the SMED method is 29.55% (Table N ° 38), a value very close to that established by the indicator. However, it still does not comply with the optimal 30% even though all the necessary considerations were taken so that the model could run and give the most accurate value.

INDICATOR	DESCRIPTION	RESULT	ALARM LEVEL			STATE
			GREEN	YELLOW	RED	
% reduction in extrusion set-up time	(Total time - Reduced time / Total time) * 100	20%	More than 20%	Between 15% and 19%	Less than 15%	RED YELLOW GREEN

Figure 18: Indicator of SMED

Source: self made

Table 8: Actual setup time vs. simulation

CURRENT TIME (min)	SIMULATION TIME SMED (min)	SAVING (min)	REDUCTION
112	78,9	33,1	29,55%

Source: self made

When the indicator was given the result of 29.55%, the state that was obtained was Yellow, which means that it is not at an optimum level. However, there is a factor that does not allow compliance with the established optimal reduction level of greater than 30%. This factor must be analyzed and an action should be recommended in order to comply with the indicator.

DISCUSSION

Based on the results of simulation, it was shown that the application of the SMED tool of Lean Manufacturing made it possible to reduce the preparation time to a time range within that specified by the extruder machine.

The revised theory of SMED stipulates that the tool should reduce preparation times of any process to a single digit amount of time in minutes. In the present case study, the preparation time of the single-digit extrusion machine could not be reduced due to the complexity of the process. However, the reduction was considerable because of the optimization of resources and the compliance with the technical specification.

Therefore, the SMED tool was successfully implemented in this plastic film production company even though the theoretical requirements of the tool were not fulfilled.

CONCLUSION

The political and economic situation of any country requires companies to be adaptable to change, making it necessary to investigate their markets, evaluate their costs and improve their processes so that they can better compete in the free market. Companies must have a marketing plan in order to respond to changes within the Peruvian market and must analyze their processes with productivity indicators as discussed in the third section of the present study. For the company examined in this study, the extrusion preparation process did not meet the time established by the indicator for this particular process.

The implementation of the SMED tool allowed for the preparation time of the extruder to be reduced from 112 minutes to 80 minutes after converting some internal activities into external activities, suppressing activities and combinations of activities to conduct in parallel.

The results of the simulation made using the Arena software indicate that the improvement project managed to reduce the configuration time of the extruder by 29.55%. This was based on the SMED considerations. The reduced time spent on material searches by the machine operators and also the improvements made to the organization and cleanliness of the workplace were ultimately not considered in the model.

According to the proposed indicators, a reduction of 30% in the time of configuration of the extruder can be achieved. However, using this proposal, it was reduced by 29.55%, a percentage close to the target. This was due to the fact that the company and the distributions of times could not be completed at 30%. This goal was given by the general management, due to the heavy investment for the implementation of Lean Manufacturing. In order to achieve a reduction of 30% or greater, the changes laid out in this proposal can be used to improve the configuration activities of the extruder machine. If possible, the configuration tasks should be analyzed again and the SMED should again be applied as the simulation always offers different results for each change that is made to the model.

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