IMPROVEMENT OF MOLD EXCHANGE PROCESSES IN AN INJECTION MOULDING PROCESS

Neutroplast Case Study

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ABSTRACT

This dissertation focuses on Neutroplast, the main producer of plastic packaging for the Pharmaceutical Industry in Portugal. With the increase in production derived from the company's internationalization, the need arose to increase the efficiency of the process. Thus, the main objective of this work is to find the main inefficiencies of the productive process and to suggest improvement proposals.

To reach the proposed objective, this dissertation begins by presenting the case study based on the company. Next, a review of the literature focuses on the "Lean Thinking" and the tools that can be useful to solve the case study. After this theoretical foundation, an analysis is made of the opportunities for improvement and the application of tools that can help to solve the problem is studied. Finally, the impact of the proposed improvements is studied.

After analyzing opportunities for improvement, it was concluded that the focus should be the mold replacement process and the SMED methodology was applied to reduce the time of these operations. It is estimated that the application of the proposed solutions results in a 71% decrease in operating time, resulting in an estimated saving of 2957 EUR per year.

Keywords: Lean Thinking; Value Stream Mapping; Single-Minute Exchange of Dies; Plastic Injection Moulding

1. INTRODUCTION

The packaging market is a global and diverse market, of which one segment stands out - the pharmaceutical industry. Being an industry with demanding regulation in order to guarantee the quality of the produced products, it is recurrent the pressure that exists to reduce costs of production maintaining the quality of the same ones. Thus, the use of techniques and tools that can be used to eliminate wastes are very important as they allow for more optimized operations and processes.

It is in this context that the present dissertation appears. The central objective is to analyze the production line of the company Neutroplast, located in Sobral de Monte Agraço, which is having difficulty responding to the increase in demand it has had. For this, the analysis is expected to find out the main points of inefficiency of the process and to study the best way to improve them.

This dissertation aimed to analyze the production line, to perceive where the process is inefficient and to suggest improvements that improve the efficiency of the system.

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In operational terms, this dissertation has several objectives, such as:

- Description and analysis of the case study;
- Select Lean methodologies and tools that fit the purposes of this dissertation;
- Analysis of opportunities for improvement in the process and propose alternative solutions;
- Impact analysis of proposed solutions to improve the process;
- Presentation of the conclusions of the work carried out and their implications.

The structure will be as the following:

- Section 2: Case Study
- Section 3: Literature Review
- Section 4: Opportunities for improvement analysis
- Section 5: Impact analysis
- Section 6: Conclusions

2. CASE STUDY

The market for plastic packaging represents a high share of the total plastics market. According to the Plasticseurope report, it accounts for almost 39% of the European plastics market.

In Portugal, given the size of the country, the market represents EUR 462 million (approximately 0.13% of the global total). One of the reference companies, which has its origins in the 80's, is Neutroplast.

Neutroplast is a company that operates in the plastic packaging market, with a focus on the Pharmaceutical Industry. With a turnover of more than EUR 5 million, of which EUR 3 million corresponds to the export of products, the company is one of the main players in the national market. After being affirmed in Portugal, the company tries to mark its position in the international market through the constant innovation and quality of its products.

Given the size of the Portuguese market, Neutroplast saw an opportunity in the internationalization of its activities for expansion and sustained growth. In addition, it considers that its products must be established at international level to increase the levels of innovation and competitiveness required of the most efficient companies.

Following this need of growth, the company looked at its processes and identified a problem in the mould change operation, since it was a time consuming operation and would be influencing the desired productivity values. It was then hypothesized that one of the main bottlenecks of the process would be in the process of changing molds.

In order to test the hypothesis raised, an analysis was made of this process to obtain a diagnosis. The analysis was performed through direct observation of the process and a study of the times obtained was done. In this analysis there was still interaction with the operator in order to understand the process, which allows a more accurate judgment about its importance for the overall process.

The results of the analysis are present in the Table 1, resulting from a total of 4 observations to the process.

Table 1 - Results of visual analysis of a mold exchange process

	Average
Time from machine stop to start of process (min)	10
Operating time (min)	124.3
Workers involved in the operation (number)	3

3. LITERATURE REVIEW

The productive paradigms have been diversifying since the end of the eighteenth century, so it is important to speak in the most current paradigm and that can contribute to the development of the company.

the work developed in this dissertation is based on Lean production, considered one of the most important paradigms in the last decades according to Holweg (2007).

Lean production was defined by Taj (2008) and Eatock et al (2009) as being a set of concepts, principles, methods and tools that work with the objective of improving various aspects of a productive process. The importance of Lean production was reinforced with Chowdary & George (2011), while extolling the importance of Lean production practices in companies by reducing production time and inventory of intermediate products (finished products that will still be used in the production process).

• Lean Thinking

According to Melton (2005), the "Lean Thinking" arose in 1940 in the Toyota car company. This approach was based on the recognition that only a fraction of the total time of product creation adds value to the end consumer. This current was contrary to the paradigm at the time that was based on the mass production developed by Henry Ford.

• Lean Principles

Responsible for the popularization of "Lean Thinking", Womack and Jones (1996) developed this methodology based on five pillars. These concepts are fundamental to understand well all the peculiarities associated with Lean Thinking:

1. Value

Value is everything that is a direct part of the product or service and is defined based on what the specific consumers of the product are looking for. Anything that does not contribute to achieving consumer expectations does not add value to the product. It is this definition that is currently used and will serve as the basis for the development of this chapter.

2. Chain Value

The value chain is defined by Rother and Shook (1999) as being the set of actions that are necessary for a product (or set of products of the same family) to flow through the main channels, from the raw material to the final customer.

Womack and Jones (1996) and Monden (2015) argue that it is possible to define three types of actions in a value chain: (1) No value added and unnecessary, (2) No added value, but necessary, (3) Value added and necessary.

3. Flow

After defining the value and value chain for a given product or service, Womack and Jones (1996) state that it is necessary to make value-creating actions work in such a way that there is no waste between the end of one and the end beginning of another. This dynamic is called Flow.

4. Pull Production

Pull Production is characterized by being a methodology where production corresponds only to what is actually ordered by the customer. This form of production means that it is not necessary to spend resources on sales forecasts since only what the consumer needs is produced.

5. Perfection

The fifth and final pillar of "Lean Thinking" is what guarantees the sustainability of production operations. Perfection must be attained from the point where the remaining pillars begin to function properly and interact with each other as a cycle. This pillar is based on the perfection of this system and its continuous improvement in order to achieve new levels of efficiency.

• Lean Tools and Methodologies

1. Value Stream Mapping

Value Stream Mapping (VSM) is an important tool used in Lean and allows mapping processes and their value chain. According to Manos (2006), this tool enables the company to plan, implement and improve its operations in order to increase its efficiency.

The value chain has two types of channels, the information channels and the material channels. The main objective of VSM is to identify all types of waste in the value chain and to promote actions to eliminate these same wastes.

For the creation of VSM, Mastroianni and Abdelhamid (2003) developed a simplistic and objective approach that focuses on content creation. Table 2 lists the six steps required to create a VSM.

Table 2 - Creation of VSM (source: Mastroianni and Abdelhamid (2003))

Step	Name	Description
1	Current State Map	The Current State Map is a document that consists of the mapping of the current flows.
2	Opportunities for improvement	The Current State Map is analyzed, the opportunities for process improvement are identified and where there is waste in the system that can be eliminated.
3	Future State Map	The Future State Map is the flow map that you want to achieve after optimizing the processes.
4	Work Plan for Future State	This step defines the work plan that needs to be fulfilled in order to materialize the Future State Map.
5	Definition of KPIs	KPIs are defined that allow you to understand when the objectives are met.
6	Cost analysis	A cost analysis is done comparing the Current State and Future State Maps to find out the difference of values.

2. Single-Minute Exchange of Dies

The Single-Minute Exchange of Dies (SMED) is a Lean tool developed by Shingo (1985) whose main objective is to reduce the time of changeover between batches of production of different products. The goal is that the setup time is less than 10 minutes. In his work, Shingo (1985) distinguishes three steps in the methodology of application of SMED, in addition to a preliminary step to the process.

The preliminary step consists of an introductory evaluation of the process, where an overall view of the process and its constituent operations is achieved. In this step, several techniques are recommended for this analysis such as the use of a stopwatch, the study of the method, interview with operators or even use of process filming. The goal is to be able to decompose the setup process into elementary setup operations, which are then analyzed and changed.

In the first step, the operations that were previously defined are characterized and a classification is made taking into account whether the operation needs to be performed while the machine is running or not. If the operation is performed while the machine is running, then it is an external operation (external setup). Otherwise, if the operation can only occur while the machine is running, it is classified as internal operation (internal setup).

The second step is to analyze the internal operations so that they can be converted into external operations. This step consists of two steps: first, a process analysis must be done again to see if there are any operations that have been misclassified previously. After this analysis, it is necessary to understand how best to convert internal operations to external ones. The purpose of this phase is to identify the internal operations that will be converted.

In the third and final step, Shingo argues that it is here that "systematic improvement of each basic operation of internal and external setup" takes place. This translates into the implementation of the improvements suggested in the previous step and the careful analysis of all the operations of the process to see if there are more opportunities for improvement. There is a focus on reducing time primarily in internal operations. Since this is a tool for continuous improvement, and when it is applied there must be a constant search for the optimization of the operations involved, it is at this step that we aim to achieve the fundamental goal of SMED - the single minute for setup time.

Several case studies, that were based on a similar problem to the case under investigation, were analyzed. This analysis proved to be very important in the scope of this dissertation, since it allowed to draw conclusions that will be relevant in the implementation of the methodology present in this dissertation. Several conclusions were drawn from the cases analyzed. The most relevant are the following:

• As seen in Kays and Kara (2007), the fact that it has achieved a high reduction (from 365 to 73 minutes) but still far from the one recommended by the tool (10 minutes) indicates that success is relative and does not depend only on achieve the single-minute goal.
• The importance of the involvement of production operators is sometimes underestimated. It was concluded that it is very important that operators are involved in the application of the SMED tool, since they can suggest excellent suggestions for improvement, being more receptive to the implementation of new ways of working.

• Finally, it was concluded that in CNC systems it is possible to obtain very good results with the application of SMED, achieving very high waste reductions compared to other systems. However, since Neutroplast already has a set of traditional machines and is in a situation of cost reduction and with already restricted margins, not all the costs inherent in the acquisition and maintenance of the new machines are justified. Thus, in the present case, it is not justified to study the application of SMED in CNC machines.

4. OPPORTUNITIES FOR IMPROVEMENT ANALYSIS

In this chapter we begin the study of the process described in the chapter of the case study

First, a mapping of the production process is done so that it is possible to identify which operations are not efficient at all. Then, once the improvement point is identified, some Lean tools are used to help minimize the problem.

In this chapter the objective is, after identifying the operations that need to be improved, develop an action plan that can be implemented in the future.

4.1 Current State Map

The current production process was designed and a VSM was created, adapted to the actual situation of the process, which can be consulted in Figure 1. Due to the fact that some data could not be obtained, adjusted average times were used to obtain a more accurate view of the state of operations.

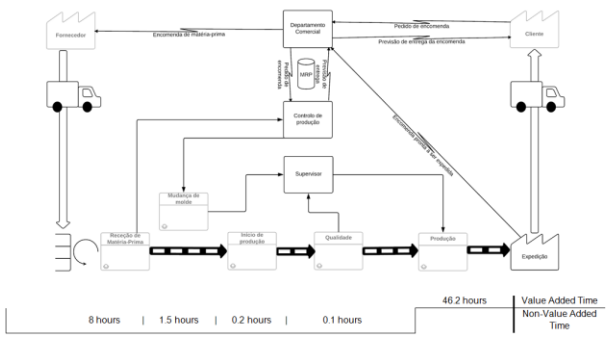

Figure 1 – Current State Map

After analyzing the process mapping described in 4.1, it is concluded that the main target point for improvement is the process that occurs when there is mold change. Based on the reviewed literature, the most effective tool to optimize this process is SMED.

4.2 Application of SMED

The implementation of the SMED method in the mold change process aims to reduce the time and increase productivity. Considering that the SMED method is applied taking into account the specificity of each case study and that, the method is flexible, the methodology applicable in this work is, according to what is referred to in the literature review, performed in four steps:

- Preliminary step: in this step the operations that make up the process are recorded and will serve as a basis for the application of this continuous improvement tool. The time was calculated based on the calculations made in 2.3.2 and the process will be decomposed into its elementary operations.

- First step: in this step the separation between internal and external operations is performed and the result is the separated process by operation and its classification (internal or external).

- Second step: This step corresponds to the analysis of internal operations so that they can be converted into external operations. Firstly, a reassessment is made of the process to verify that the classification of operations is correct and then the best way of converting the internal ones to external ones is analyzed. The result of this step is the process with internal operations converted and optimized.

- Third step: in this step the improvements suggested in the previous step are implemented and the internal operations are optimized, so as to define a fluid process and a shorter operating time than the initial process.

4.2.1 Preliminary Step

As mentioned earlier, this step is characterized by an introductory evaluation of the system that serves as a starting point for the application of SMED. This phase was achieved through the direct observation of the mold exchange process and the use of a chronometer for counting times. In addition, filming was used for a better observation and distinction between the operations that make up the process. The results are shown in Table 3.

Table 3 - Mold exchange operations of the DEMAG II machine on July 10, 2017

Sequence number	Operation	Time (hh:mm:ss)	
		Operation	Cumulative
1	Machine stop	-	0:00:00
2	Removal of refrigeration tubes [old mold]	0:02:50	0:02:50
3	Hook placement [old mold]	0:00:30	0:03:20
4	Tool carriage collection	0:00:40	0:04:00
5	Removal of claws that hold the mold [old mold]	0:02:28	0:06:28
6	Opening more space for mold [old mold]	0:00:50	0:07:18
7	Withdrawal of the old mold [old mold]	0:01:55	0:09:13
8	Placing the hook in the new mold [new mold]	0:00:22	0:09:35
9	Placing of new mold [new mold]	0:02:40	0:12:15
10	Mold Center [new mold]	0:02:25	0:14:40
11	Mold height and length adjustment	0:07:59	0:22:39
12	Fixing of clamps [new mold]	0:05:28	0:28:07
13	Removing the safety bar [new mold]	0:00:40	0:28:47
14	Pitch adjustment	0:02:18	0:31:05
15	Connection and testing of cooling channels	0:17:10	0:48:15
16	Extraction of radial	0:06:14	0:54:29
17	Setting production parameters	0:07:40	1:02:09
18	Heating channels connection and testing	0:07:01	1:09:10
19	Setting production parameters	0:02:15	1:11:25
20	Toolbox storage	0:00:30	1:11:55
21	Production (product for quality)	0:17:00	1:28:55
22	Quality Analysis	0:05:00	1:33:55
23	Start of production	-	1:33:55

The Preliminary Step is concluded, and now the First Step begins.

4.2.2 First Step

In this first step, the distinction between internal and external operations is made, recalling its previously studied definition.

After the distinction was made, operations were aggregated to determine the time spent in each typology. The result is in Table 4.

Table 4 – Operations according their classification

	Accumulated Time	% Process Time
Internal	1:17:20	82%
External	0:16:35	18%
Total	1:33:55	100%

As can be seen in Table 4, about 18% of the replacement time of a mold is spent on operations that could be performed while the machine is in operation. According to Cakmakci (2008), this step aims to reduce between 30 and 50% of the setup value. This means that the expected value of percentage of the time of the external operations should be between the mentioned intervals. Nevertheless, although the value obtained does not fall within these parameters, the distinction between external and internal operations indicates that the focus should be the elimination of external operations, in order to reach the value obtained in Table 4.

There are some solutions that can be used to eliminate the external activities of the process, and the main one is the use of a check list. This tool allows the operator to know in advance which tasks to perform before and after stopping the machine.

For this case study, this document was developed. Thus, the goal is for the operator to follow the checklist and fulfill all requirements. After that, he submits the form to his supervisor who validates that the process was followed according to the recommended one.

This solution allowed updating the procedure so that it only includes internal operations. The remaining operations will be done before and/or after the machine is stopped. The updated procedure can be found in Table 5.

Table 5 – Process after First Step of SMED

Sequence number	Operation	Time (hh:mm:ss)	
		Operation	**Cumulative**
-	Hook placement [old mold]	0:00:30	-
-	Tool carriage collection	0:00:40	-
-	Setting production parameters	0:09:55	-
1	Machine stop	-	0:00:00
2	Removal of refrigeration tubes [old mold]	0:02:50	0:02:50
3	Removal of claws that hold the mold [old mold]	0:02:28	0:05:18
4	Opening more space for mold [old mold]	0:00:50	0:06:08
5	Withdrawal of the old mold [old mold]	0:01:55	0:08:03
6	Placing the hook in the new mold [new mold]	0:00:22	0:08:25
7	Placing of new mold [new mold]	0:02:40	0:11:05
8	Mold Center [New Mold]	0:02:25	0:13:30
9	Mold height and length adjustment	0:07:59	0:21:29
10	Fixing of clamps [new mold]	0:05:28	0:26:57
11	Removing the safety bar [new mold]	0:00:40	0:27:37
12	Pitch adjustment	0:02:18	0:29:55
13	Connection and testing of cooling channels	0:17:10	0:47:05
14	Extraction of radial	0:06:14	0:53:19
15	Heating channels connection and testing	0:07:01	1:00:20
16	Production (product for quality)	0:17:00	1:17:20
17	Start of production	-	1:17:20
-	Toolbox storage	0:00:30	-
-	Quality analysis	0:05:00	-

4.2.3 Second Step

In this step the conversion of internal operations into external ones is done. Since no internal operations can be converted, the third and final step of SMED is carried out.

In addition to the conversion of operations, a reassessment of its classification is given. Following a meeting with the Neutroplast team regarding the implementation of Step Two, it was concluded that it would not be necessary to re-evaluate the classification of operations.

Since there are no actions to be carried out during this step, the third and last step is presented.

4.2.4 Third Step

In this final step, the goal is to optimize the internal operations, since the external ones have already been improved in the first step. The goal is to minimize your runtime. To achieve this goal, we use different tools.

The use of different tools is crucial to the successful application of SMED to any production line. Although there is an initial investment that can be high in terms of reduction of setup is proven (and can be consulted in literature review) which is very advantageous.

We have identified some operations that can be improved with two different tools: the multi-couplers and the magnetic clamping system.

- Multi-couplings

The multi-couplers are systems that allow the reduction of the time of connection of the refrigeration and heating tubes between the production machine and the mold. This option arises since as can be seen from Table 3 these operations have a high execution time.

It is envisaged that the use of these couplers would allow a high reduction of process operating time, and this is confirmed in EAS (2007) where it is stated that this replacement is done in approximately 3 minutes. There is no information on Stäubli equipment in this respect.

- Magnetic fastening system

The Magnetic Anchoring System aims to make the operations for the fastest mold placement and removal phases, eliminating the need to adjust the fasteners and facilitating mold positioning operations on the machine. Since the EAS does not offer a similar solution, the Stäubli QMC 122 system is proposed.

Stäubli QMC 122

This system has a memory that allows to save the parameters of each mold so that when the mold is inserted in the machine, the system is activated, and the mold is fixed. In addition to the mold positioning function in the machine, the system continuously monitors the mold operation during the injection process.

This solution improves the time taken to position the mold. Although there is no time reduction data using this tool in a used way, after sharing impressions with Neutroplast workers it is estimated that this operation is completed in 2:30 minutes.

The introduction of new tools has a very significant impact on reducing operating time. Before the introduction of this new solution, the operations had a total of 37:25 minutes, while with the new tools these total only 5:00 minutes. We thus have an 87% reduction in the time spent on these operations. As will be seen later, this reduction of 32:25 minutes in operating time will have a significant impact.

The result of SMED implementation is a smoother process with less execution time while the machine is stationary. The improved process can be seen in Table 6.

Table 6 - Optimized process

Sequence number	Operation	Time (hh:mm:ss)	
		Operation	Cumulative
-	Hook placement [old mold]	0:00:30	-
-	Tool carriage collection	0:00:40	-
-	Setting production parameters	0:09:55	-
1	Machine stop	-	0:00:00
2	Removal of claws that hold the mold [old mold]	0:02:28	0:02:28
3	Opening more space for mold [old mold]	0:00:50	0:03:18
4	Withdrawal of the old mold [old mold]	0:01:55	0:05:13
5	Placing the hook in the new mold [new mold]	0:00:22	0:05:35
6	Placing of new mold [new mold]	0:02:40	0:08:15
7	Mold position adjustment [new mold]	0:00:30	0:08:45
9	Fixing of clamps [new mold]	0:05:28	0:14:13
10	Removing the safety bar [new mold]	0:00:40	0:14:53
11	Pitch adjustment	0:02:18	0:17:11
12	Connection and testing of cooling and heating channels	0:02:00	0:19:11
13	Extraction of radial	0:06:14	0:25:25
14	Setting production parameters	0:01:30	0:26:55
15	Start of production	-	0:26:55
-	Toolbox storage	0:00:30	-
-	Quality analysis	0:05:00	-

5. Impact Analysis

After developing an action plan that culminated in the proposal for an optimized process and with the clear separation between internal and external operations, this chapter analyzes the impact that the proposed improvements have on the process.

5.1 Future State Map

The first vector of analysis of the impact of the proposed solutions is done through the VSM of the Future State expected with the changes suggested previously. As previously done, two flows will be analyzed: information flow and material flow. The VSM - Future State can be found in Figure 2.

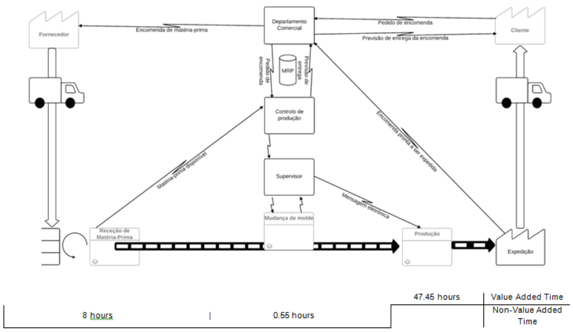

Figure 2 – Future State Map

5.2 Operation Time

After realizing the impact of the application of SMED on the overall production process of Neutroplast, it is important to make a timely analysis of the mold change operation and to summarize, in a simplified way, the gains that are achieved after each step of the SMED methodology.

In Table 7 an analysis is made to the operating times of the various SMED application steps.

Table 7 – Variation of time along SMED's steps

	Preliminar Step	First Step	Second Step	Third Step
Time (hh:mm:ss)	01:33:55	01:17:20	01:17:20	0:26:55
Variation	-	-19%	-19%	-71%

As can be seen, there is a further reduction at the end of Step Three. It is important to remember that the First Step corresponded to the elimination of external operations and the Second Step to the conversion of internal operations to external ones, which did not happen. In Step Three, we then optimized and improved internal operations.

Thus, it is concluded that the application of SMED to this mold-changing process can reduce the operating time by 71%. This reduction translates into greater use of industrial machines, greater use of human resources and an increase in production capacity.

5.3 Distance traveled by operators

Another point of analysis is the distance traveled by operators. Since the lower the distance traveled, the less time spent in operations that do not add value to the process, it is important to make an analysis that compares the distance traveled by the operators before and after the application of the SMED process.

A study will be done comparing the achievement of a reduction of 45% and 60% in the distance traveled by employees. This study allows to estimate with greater what would be the reduction in this parameter if the current SMED procedure was implemented. The values are presented in Table 8.

Table 8 - Estimated reduction of distance traveled

	Steps (number) Real Value	Time (minutes) Estimated Value	Distance (m) Estimated Value
Values before SMED	737	5.62	562
Values assuming a 45% reduction	-	3.09	309
Values assuming a 60% reduction	-	2.25	225

For the estimated calculations of time and distance, once mediation has been done in "steps," the values in Table 8 assume that the average walking speed is 6 km per hour and that 1 step is equal to 0.762 meters.

From this analysis we conclude that a reduction of approximately 3 minutes is achieved in each mold exchange process.

5.4 Analysis of employee availability

The calculation of the reduction of distance traveled by operators is important, but it is equally important to realize how the application of this methodology reduces the time spent by workers in this process. In other words, realize how much increased availability they earn and allow them to develop other operations.

Another factor that can be analyzed to measure the impact of the application of SMED to this process of change of molds is the availability of the collaborators.

By reducing the time spent in the mold change process, operators can use the "gain" time on other value-added tasks.

Prior to the application of the SMED process, this process had a duration of 1:33:55h, which corresponds to approximately 94 minutes.

Based on these assumptions and considering that at the end of the application of the third step of the SMED method the process lasts approximately 27 minutes, it is verified that there may be a reduction of 67 minutes per process.

Therefore, considering that there are 12 mold changes per month, savings of 804 minutes (13.4 hours) per collaborator are projected, translating into a reduction of 2412 minutes (40.2 hours) per month in this single process.

The occurrence of 12 mold changes per month is variable and depends on the production planning of a given month, but assuming this value as an average value and considering that the plant has no production in the month of August, it is estimated that the application of this result in savings of more than 442 hours per year.

5.5 Financial Impact Estimate

The financial impact of increasing availability is an interesting exercise to do. However, because of the availability of the cost per hour of each worker, it is necessary to assume some assumptions for the calculation of this value. It is already assumed that the savings will refer to the increase in availability in 442 hours per year, as calculated in 5.4.

- Base Salary

In the absence of official Base Maturity data from Neutroplast workers, it is preferable to make an estimate below the actual value. Thus, it is assumed that the operators receive the national minimum wage, which in the present year of 2018 is situated at 580 euros per month. Since an official receives a 14-year salary per year, his annual cost is EUR 8120.

At 2210 hours work is necessary to deduct holidays and bank holidays:

Holidays: 22 days x 8.5 hours = 187 hours

Professional training (compulsory by law) = 35 hours

Bank Holidays: 13 holidays x 8.5 hours + 1 (Christmas Eve which is granted by Neutroplast) x 8.5 hours = 119 hours

Thus, the total number of hours worked equals 1869 and the cost of each worker per hour, EUR 4.34.

- Fixed costs

In this installment, three fixed costs are considered: Social Security, Work Insurance and Food Allowance.

In May 2018 the contribution rate for Social Security stands at 23.75%. Assuming the previously calculated hourly amount, this fixed charge has the value of 1.03 EUR per hour.

The amount payable by workers' insurance is variable. As a reference, and remembering that a deduction is being made, a value of 1% will be assumed as the average value of the insurance, which accounts for 0.04 EUR per hour for the cost of the worker.

Lastly, the minimum food allowance defined by law is, in May 2018, 4.77EUR per day. Since each work day is 8.5 hours, then the contribution of the feed allowance is 0.56 EUR per hour.

Adding the three variables that make up the share of fixed charges, the value of EUR 1.63 per hour is obtained.

- Variable costs

Hygiene and Safety at work: according to Neutroplast, approximately EUR 1000 is spent annually to ensure compliance with the law in this chapter. Therefore, the contribution of this amount is EUR 0.53 per hour.

Vocational training: According to the company, to ensure that it fulfills the obligation to provide 35 hours of vocational training annually, the company contracts services worth EUR 350 (assuming a cost of EUR 10 per hour). Thus, the contribution is equal to EUR 0.19 per hour.

The sum of variable charges is EUR 0.72 per hour.

After analyzing the three installments that make up the cost of each worker, per hour of work, the value of 6.69 EUR is obtained.

Finally, once the increased availability of each worker has already been obtained in 5.4, the financial impact of increasing worker availability is calculated. Like this,

Financial Impact = 6.69 EUR x 442 = 2957 EUR

6. CONCLUSIONS

This dissertation aimed to analyze the production line, to perceive where the process is inefficient and to suggest improvements that improve the efficiency of the system. For this, a case study was used as a basis in which a brief description of the problems found in the process is made and a basis for analysis is proposed.

The work developed began with a review of the literature that could be relevant to the development of the case study. Information was collected on Lean Thinking, the Just in Time production concept and some Lean Tools such as VSM and SMED. We also analyzed several case studies that had similar problems, where similar problems were solved in the case study.

Following the literature review, a mapping of the processes was developed and a VSM of the Current State was created. After this mapping, it was confirmed that it is in the mold change that lies the main target of improvement. As such, it was decided to apply the SMED tool as previously studied in the literature review.

The application of SMED began with a Preliminary Step, which surveyed all the elements of this mold change process. The separation of internal and external operations was then made to understand how much time the process was spent in operations that were being done while the machine was unnecessarily running. Thus, the First Step of SMED application showed that 18% of the time was being spent unnecessarily.

The next step has two main objectives: to analyze the internal operations to study if it would be feasible to convert them into external ones and still to reassess if its classification was correct. As there were no internal operations that could be converted, and the classification was well done initially, this step was concluded and the third and final phase of SMED implementation started.

In this last step we proceeded to the optimization of the internal operations of the process, using different tools. After analysis, there are two tools that can contribute to the optimization of the time of some operations: the multi-couplers, which facilitate the connection of the cooling and heating tubes to the mold, and the magnetic fastening system, which allows easy adjustment the positioning of the mold when it is replaced.

Because of the SMED application, a process lasting 28:55 minutes was obtained.

Having analyzed the opportunities for improvement, the impact of this improvement on the company was analyzed:

• From the comparison between the VSM - Present State and Future State (proposal of this work) of the Neutroplast production process, it is concluded that the change in the mold change process allows a reduction of 2.2% in the production time.

• In relation to the impact analysis in operating time, a comparison was made with the initial situation. Thus, the implementation of the suggestions present in this work leads to a process with a duration of approximately 28:55 minutes, which corresponds to a reduction of 71% in relation to the initially determined value.

• In the distance traveled by the operators, it has been verified that in the current scenario they cover approximately 737 steps, the equivalent of 562 meters. After this suggestion of improvement, it is estimated that the distance is reduced to a value between 225 and 309 meters.

• The various solutions proposed also have an impact on the availability of workers. It is estimated that each employee will waste 7.6% of his or her available time on operations that are done monthly when production is unnecessarily stopped. This translates into 13.4 hours for each employee, which translates into an estimated saving of over 442 hours considering the three operators involved in the process.

• Finally, an analysis of the financial impact was made considering the increase in the availability of the workers resulting from the analyzes made previously. Based on some financial assumptions and after a survey of the costs that the company has with each worker, it was possible to estimate a saving of EUR 2957 per year

6.1 Future Work

As can be seen throughout this study, the application of the SMED methodology to the production process of Neutroplast requires not only procedural changes but also presupposes the adoption of new behaviors by the collaborators.

Because this is the first in-depth study of the production process of Neutroplast and given the enormous challenge that the company and the industry are facing, this work should serve as a starting point for further studies and analyzes. We highlight three studies that may emerge from this work:

• Implementation and comparison of the results obtained experimentally
• Study of the implementation of CNC machines
• Study of the impact of the human factor in operations

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