

Plastic compounding optimization through Lean manufacturing techniques

Alexandra O. Carreira^a, João C. M. Bordado^a, Carla A. F. Ventura^b

^aInstituto Superior Técnico, Universidade de Lisboa;

^bCabopol – Polymer Compounds, S.A., Leiria

ABSTRACT

In a period of severe economic crisis and an increasingly competitive market reality, it is vital that companies increasingly bet on improving its production processes. Polymers have been continuously replacing materials such as metals, glasses and paper due to their varied and interesting characteristics, as well as their low cost. In this context, there is an opportunity to optimize the process and increase overall productivity in Cabopol – Polymer Compounds, S.A., an enterprise dedicated to the production of thermoplastic and crosslinked compounds. To this purpose, the company resorted to the introduction of Lean Manufacturing Techniques (LMT) in the formulation lines of PVC compounds, in order to improve and increase their productivity levels, studying and analyzing the production process and identifying the main wastes points. Among the main LMT's implemented were the spread of Kaizen philosophy (continuous improvement) on shop floor, the application of 5S technique and visual management in the organization of workspaces, the use of SMED technique in reducing production downtime, the establishment of an autonomous maintenance program and the introduction of key performance indicators, namely OEE. The key performance indicators, monthly monitored, showed that the approach and methods implemented were effective, according as the improvements observed in the industrial results. OEE increased and downtimes decreased progressively during this study. Thus, also in Cabopol, Lean techniques are shown as an asset. In this sense, and taking into account the continuous improvement policy of Cabopol, the application of LMT's for all the production lines of the company is highly recommended.

Keywords: Lean Manufacturing, wastes, plastic compounds, continuous improvement.

1. Introduction

Taking into account the current economic climate, to take a prominent position in the markets in which they compete, companies must seek to implement measures and efficient solutions in increasing productivity, without the need to apply big investment. Among these measures and solutions stand out the principles of Lean Manufacturing, widely recognized as efficient methodologies for the evaluation of production processes. In particular, by promoting a culture of adaptation to change, these techniques identify wastes and establishes techniques aimed to their reduction or elimination. In short, the Lean philosophy involves the constant pursuit of perfection to production processes, sustaining a permanent attitude of continuous improvement. [1]

Cabopol – Polymer Compounds, S.A., an Iberian leader enterprise dedicated to the production of thermoplastic and crosslinked compounds, resorted to the introduction of Lean Manufacturing Techniques in the formulation lines of PVC compounds, in order to improve and increase their productivity levels. This work was carried out on PVC production lines in factory 1 of Cabopol.

2. Literature Review

2.1. Changes in production systems

Over the decades, production systems have been facing profound changes according to the continuous demand of market. The evolution of production systems include the craft production system, the mass production system and Lean Manufacturing. [1] By addressing the limitations of craft

production, the industrial revolution has introduced the mass production system, characterized by the production of large batches and only a very limited range of products, at the lowest possible price. [2]

In mass production, highly skilled professionals are responsible for the development and projection of products, while workers with lower levels of qualification perform very repetitive tasks in very specialized and automated machines. The low flexibility of the processes made product changes quite expensive, which turns the production of large batches as a preferable industrial approach. This system provides low priced products, at the expense of variety and often quality.

The more recent Lean production system, which aims for the implementation of Lean Manufacturing Techniques, makes use of the advantages of craft production and mass production, eliminating the inflexibility of mass production and the high production costs associated with craft production (colocar ref) The Lean production system is characterized by the constant search for waste by teams of multi-skilled workers at all levels of the organization. The processes are highly flexible, allowing the production of a wide variety of products. Figure 1 resume the changes in production systems over centuries.

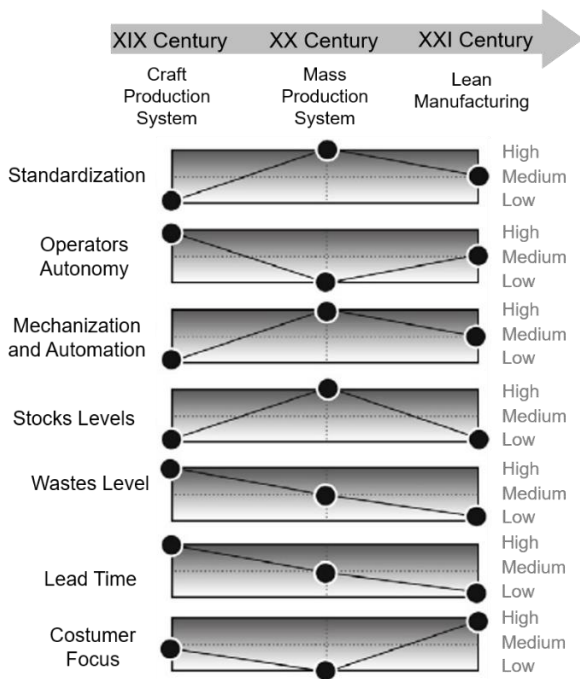


Figure 1 – Changes in production system (adapted from [1]).

2.2. Lean Manufacturing and Relation with Waste

Lean Manufacturing has its roots in the Toyota factory, in Japan, at the end of World War II, with the development of the Toyota Production System (TPS). The TPS was born from the combination of mass production virtues, practiced at the time in the West, with the existing Japanese production techniques. Its introduction transformed a once poorly flexible industry with high investment costs and need for specialized personnel, in response to global competition and the increasing demand for much diversified products [3]. Their method consists in the simple concept of producing under continuous flow, without relying on high production times, providing a high variety of low-priced products. [2][4]

The adoption of a Lean system promotes a change in the management of productive operations and it aims for the reduction or elimination of waste, namely by process optimization. The effects of its implementation could increase the productivity of the production process, reduce setup times, lower stock levels of finished product, and ultimately increased customer satisfaction. [3] The effort of implementation of LMT's will lead to the achievement of small improvements, that despite requiring low financial investment, translate into very significant cumulative benefits, that, in most cases, are more significant than high financial investment innovations. [5]

Waste refers to all activities that consume time and resources and do not add value to the final product. Basically, wastes are activities that do not create value and, instead, have costs for the organization. The seven potential groups to the occurrence of waste are: transport, inventory, motion, waiting, over processing, overproduction and defects. [3][6][7] The **transport** waste comprises all the movement necessary to transport goods and is mainly caused by poorly designed layouts, whose result is the

unnecessary movement of materials or equipment. The **motion** waste refers to the movement of operators in performing tasks and is mainly related to the positioning of tools, equipment location and ergonomic aspects of equipment; the **waiting** waste is associated with the equipment, materials and / or labor-work waiting time, by subsequent phases of the process; the **inventory** waste occurs when there is accumulation of finished or semi-finished materials in quantities greater than those actually needed. Higher stock levels translates to an inappropriate use of storage space and immobilize capital; the **over processing** waste refers to processes, operations and unnecessary activities in the production process and the use of equipment dimensioned in an expropriate way; the **overproduction** waste is related with production surpluses, in the wrong amount or the wrong time (earlier than expected). Lastly, waste caused by **defects** arise from the production of products outside of specifications and customer needs, causing reprocessing or scrap. More recently, a new type of waste, related to the **creativity of operators**, has been described (ref). [8] It has been argued that the promotion of a culture of self-improvement and creativity by the operating staff, which deals closely with the processes every day, could be very useful in the identification and elimination of the seven previously mentioned types of waste. [9]

2.3. Kaizen: the continuous improvement model

Kaizen comes from the fusion of two Japanese words: Kai stands for "change" and Zen stands for "for the good" or "the best". Therefore, it is defined as a methodology that aims for the achievement of low-cost rapid improvements, making use of common sense and creativity to optimize production processes. [5] Kaizen should be focusing in guemba (shop floor), since it is the place where the production process is and where the value is generated.

2.3.1. PDCA cycle

PDCA cycle is a support tool to Kaizen implementations. The initial PDCA refers to four activities: Plan, Do, Check and Act. The PDCA suggests that the steps taken towards the implementation of improvements are accompanied by the four phases of the cycle, which must be continually repeated until perfection is reached. [5]

2.4. Lean Techniques

2.4.1. 5S

The 5S concept is defined as a continuous improvement methodology that aims to motivate and raise awareness to the importance of keeping the workspace organized and standardized. [10]

5S derives from five sequential and cyclical activities beginning with the letter "S", which translated means: sort (seiri) – remove unnecessary items; straighten (seiton) – arrange the items so they can be easily picked; shine (seiso) – clean the workplace;

standardize (seketsu) – maintain the three previous 4 steps; and sustain (shitsuke) – keep all the standards in order. [11]

2.4.2. Visual Management

The goal of visual management is to make problems and waste visible and raise awareness for their elimination. It comprises a series of visual signaling techniques to expeditiously identify the conditions of processes and operations. There must be implemented ways to control processes such that the problems and deficiencies are visible and are readily identified, thus increasing the response speed. [5]

2.4.3. Autonomous Maintenance

Autonomous Maintenance (AM) represents one of the eight pillars that form Total Productive Maintenance (TPM). TPM comprises a set of strategies aimed at maximizing the efficiency of production systems, eliminating any kind of loss in order to achieve "zero defects, zero faults and zero accidents". [12] In AM, the equipment operators perform routine inspection tasks, adjustment or cleaning, that were previously carried out by operators of maintenance. Thus, the maintenance operators have more time for driving continuous improvement activities that require further analysis. [13]

The steps for the implementation of autonomous maintenance comprises [14]:

1. Cleaning and initial inspection;
2. Eliminate sources of contamination and hard to access locations;
3. Establish standards for the inspection of equipments i and respective cleaning;
4. Drive the general inspection of the equipment;
5. Perform general inspection in the process;
6. Systematization of the Autonomous Maintenance;
7. Self-management practice.

2.4.4. OEE – Overall Equipment Efficiency

From the TPM program comes the notion that it is essential to establish a comprehensive way to measure performance and capacity utilization, in a perspective that what is not measured can not be improved. In this context, the OEE is used as metric to measure overall equipment efficiency. [15] The equipment losses result in different types of waste, defined as activities that consume resources but do not create to the finished products.

The calculation of OEE takes into account six basic types of equipment waste, grouped into the following three classes [12]:

Availability losses

- A1. Unplanned stops
- A2. Planned stops

Performance losses

- B1. Small stops
- B2. Slow cycles

Quality losses

- C1. Startup rejects
- C2. Production rejects

The value of the OEE is calculated by multiplying three indicators - availability, quality and performance –, which consider the impact of six major losses on the overall performance of equipment, as follows. [16]

$$\text{OEE} = \text{Availability} \times \text{Quality} \times \text{Performance} \quad \text{Eq. 1}$$

The relationship between the composition of the equipment time and OEE indicators, as well as the calculation method of each indicator is outlined in Figure 2.

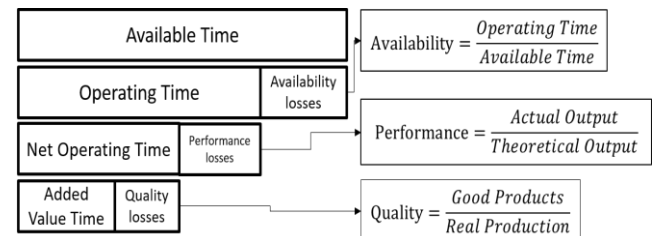


Figure 2 - Relationship between the composition of the equipment time and OEE indicators.

The basic model of the OEE calculation proves to be ineffective in the efficiency evaluation of a single equipment. However, a simple extension of the evaluation of a production system consisting of several equipments is not enough when one wishes to target his overall improvement. To measure and optimize a process consisting of more than one equipment, such as a production line, the measurement of OEE shall be in bottleneck. [17]

2.4.5. SMED – Single Minute Exchange of Die

SMED is a technique that aims to reduce the time needed for equipment setup. Setup stands for activities that involve the preparation and adjustment parts or equipment before, during and after production start. Within the setup operations, the tasks are divided into two classes: internal activities - setup activities carried out while the machine is stopped - and external activities - setup activities carried out while the machine is running. The implementation of SMED requires four stages, namely: **preliminary stage**: observe the current methodology; **stage one**: separate the external and internal activities; **stage two**: convert internal activities into external activities; **stage three**: optimize all activities constantly. [18]

3. Case Study at Cabopol - Polymer Compounds, S.A.

3.1. PVC compounding production process

The PVC compounding comprises five principal steps: raw materials mixture, mixture cooling, extrusion, granulation and granulation drying.

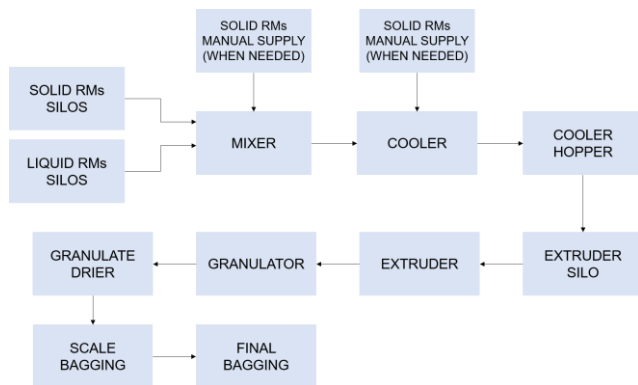


Figure 3 – Simplified block diagram of PVC compounding process.

The three PVC production lines are served with an automatic RMs feeding system, shared by the three production lines.

3.2. Bottleneck analyses

The flow of PVC compounding process should be continuous from the silo of the extruder. However, there are several limitations in the process that sometimes require the stoppage or speed reduction of the extruder due to lack of material in the extruder silo, namely:

- **Mixer limitations in load capacity:** the correct performance of mixer implies that it is loaded with a volume of mixture equivalent to one third of its total volume.
- **Limitations on mixer and cooling processes:** this aspect does not depend on the mixture times but on the efficiency related to the defined process temperatures.
- **Limitation of the scale weighing capacity:** often one batch cannot be scaled in one time.
- **Limitation on the transport of mixtures from the hopper to the extruder silo:** this aspect is related to the existence of only one compressor serving all three PVC lines.

On the other hand, also in downstream of the extruder, there may be process limitations, in particular on the finished product packaging area. Namely, if there are no human resources required to maintain the flow of the process, there will be grain accumulation in the silo bagging scale, which consequently requires the reduction or stopping of the extruder activity.

3.3. Downtimes analyses

The downtimes represent waste that results in production losses. The downtimes study is a very effective method in the identification and prioritization of the production losses, which, after analysis, are subjected to measures designed to reduce or eliminate them.

The downtime causes, recorded in PVC production lines in the first quarter of the year, were studied. Table 1 registers the top five downtime causes, ordered by non-productive times. The percentage of each downtime values are relative to the total downtimes and the percentage of frequency is relative to the total frequency of downtimes recorded in the period under review.

Table 1 – Top 5 downtime causes in PVC production lines.

Downtime Cause	Downtime (%)	Downtime Frequency (%)
Production line clearance	61,5	25,9
Screen pack cleaning and changing	14,4	44,9
Insufficient supply of material in extruder	5,1	6,1
Extruder decompression system cleaning	4,3	8,5
Knives exchange	3,2	7,0

The mentioned downtimes represent routine tasks conducted by the machine operators and will be the subject of study in order to optimize the associated downtime and the frequency of occurrence, making the process faster, more efficient and standardized.

3.4. Lean techniques selection

In order to face the identified wastes, a selection of the following lean techniques was made:

Kaizen: Dissemination of the culture of continuous improvement on shop floor;

5S: Standardization and organization of working places, making the operations involved in the production process more agile and efficient;

Visual management: Allows an intuitive detection of abnormal conditions, permitting keener agility in tasks performance and in the standardization of processes;

Autonomous maintenance: Provides the operators with autonomy to inspect critical points of the machines and know-how in the reaction to the deviation of operating conditions. Establishes a communication system between maintenance and production that allows a correct transmission of information between the two departments;

SMED technique: Observation, in detail, of routine tasks performed by operators for further optimization, namely, by reducing the associated downtimes;

OEE calculation: Introduction of the calculation of OEE in the factory as a measurement of implemented actions effectiveness and as an identifier of opportunities for improvement in the processes.

3.5. Lean techniques implementation

3.5.1. Daily shop-floor meetings

The spread of Kaizen culture in the factory began with the introduction of daily meetings in shop floor, in order to develop the spirit of teamwork and mutual support, oriented to continuous improvement and constant seek for waste.

A multidisciplinary team was defined and structured with people who daily contact with shop floor. In this sense, it was defined a representative of each department (production, maintenance, quality and planning) to join the team of the daily

meetings, along with the shift leader and the continuous improvement coordinator. The main function of continuous improvement coordinator, besides ensuring the follow-up of continuous improvement actions, is to act as a precursor to the change of culture, valuing people and their ideas and creating an appropriate environment so that these could develop improved skills in the area.

Daily meetings are held once a day early in the morning and have a stipulated duration of ten minutes. The main objectives of the meetings are the focus on the analysis of the difficulties experienced the previous day, the variations in production compared to what was forecasted by the planning and the presentation and discussion of KPI's. The direction aligns the shift leader, broadcasting the day's goals to be achieved. Also, the shift leader is free to suggest improvements that in his point of view optimize tasks, processes and operations and make working methods more efficient and streamlined.

In view of the discussed difficulties and problems, the respective causes are sought and analyzed. After this, solutions to eliminate them are established and then the plan of Kaizen actions is defined, monitored by the PDCA cycle. Kaizen board was created so that everyone can access to ongoing action plan and the values of KPI's (see Figure 4).



Figure 4 – Kaizen board.

3.5.2. 5S and visual management

The implementation of 5S methodology, combined with the visual management, arises from the need to standardize and organize workplaces, making tasks more agile and efficient. In addition to the elimination of waste resulting from poor organization of working areas, such as loss of time in the search for tools and materials, it is expected to observe change of behavior and attitude in order to create the necessary basis to enable the development and support improvements.

The 5S technique was applied to PVC production lines workbench and desks (see Figure 5 and Figure 6).

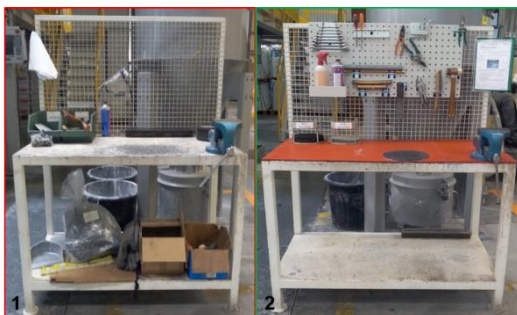


Figure 5 – PVC production lines workbench (1: before 5S; 2: after 5S).



Figure 6 – PVC production lines desks (1: before 5S; 2: after 5S).

3.5.3. TPM – Autonomous maintenance

The implementation of autonomous maintenance, provided by the TPM model, involved the execution of the seven steps described in Figure 7. Its implementation by steps allows to progressively increase participation, responsibility and knowledge of the operator by the machines they operate.

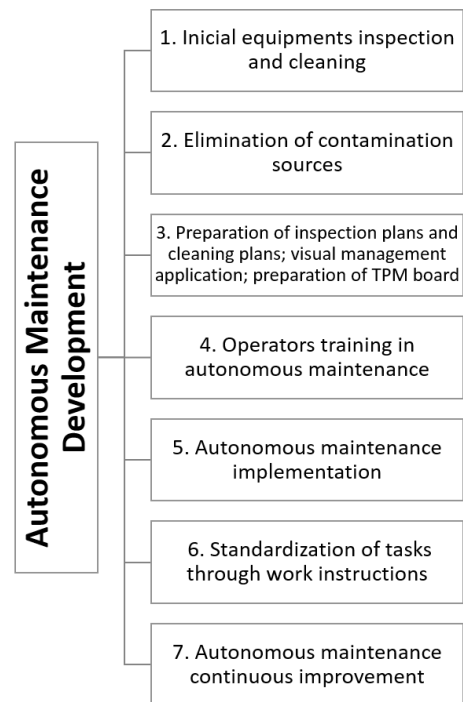


Figure 7 – Steps to autonomous maintenance development.

Operators are the best knowers of equipment and could easily detect anomalies in the process. These anomalies, as well as those detected during verification of inspection plans, should be immediately recorded and reported to the maintenance through activation of non-compliance red cards. Non-compliance red cards are filled and placed in the TPM board by the operator and subsequently evaluated by the team of maintenance, who consults the board daily.

3.5.4. SMED

All SMED analyses involved the records of tasks and informal discussion with operators. Every task was duly recorded and the SMED analysis followed the steps described in section 2.4.5.

3.5.4.1. Screen pack cleaning and changing

The frequency of screen pack cleaning and change is defined and documented in procedures of factory's quality management system, constituting an inherent operation in the process, which cannot be eliminated. The analysis of the aspect of screens is part of quality team routine checks, where the presence of points of poor dispersion of the mixture, burned spots or foreign particles (wood, metal, etc.) is a quality alert for possible problems in work in progress, which can range from contamination to wrong or inadequate process conditions.

First, it was determined the average time of downtime for screen pack cleaning and changing in each production line of PVC, given the records made in the first quarter of the year (see Table 2).

Table 2 - Downtime related to screen pack cleaning and changing.

Downtime for screen pack cleaning and changing			
	PVC Line 1	PVC Line 2	PVC Line 3
Average time (min)	4	16	4

By analyzing the data presented in Table 2 it is possible to observe that in PVC line 2 the average time of downtime for screen pack cleaning and changing is four times larger than the average downtime found in PVC lines 1 and 3. This is due to the fact that the PVC lines 1 and 3 are equipped with an automatized system to do the screen exchange. Once the screen pack cleaning and changing in PVC line 2 is totally manual, the SMED analysis will be done in this production line.

It was possible to observe, through the SMED analysis that external operations involving the search for tools were occurring. These operations were eliminated through the implementation of 5S in PVC lines workbenches. Then, internal operations were studied and changes have been suggested, with optimization in the point of view. Lately, after the SMED analysis, it was found that, in theory, the new screen pack cleaning and change time was five minutes, half the time verified before the SMED intervention.

Table 3 – Scenarios when line cleaning is needed.

	Scenario	Mixer	Cooler	Cooler hopper	Extruder Unit	Granulate dried	Scale Bagging
1	Formulation change	Clean & Clear	Clean & Clear	Clean & Clear	Clean & Clear	Clean & Clear	Clean & Clear
2	Defect products due to RMs	Clean & Clear	Clean & Clear	Clean & Clear	Clean & Clear	Clean & Clear	Clean & Clear
3	Defect products due to extrusion process	-	-	-	Clean & Clear	Clean & Clear	Clean & Clear
4	Maintenance activities	Clean and clear from the maintenance activity point till the end of production line					
5	Stoppage longer than 8 hours	Clean	Clean	Clean	Clean	Clean	Clean

3.5.4.2. Knives change

The four knives, positioned at the die, are responsible for the granulation of the materials.

Throughout its use, the knives begin to wear, which could reflect on the cut material quality, verifying the burr appearance in the grain.

At this point, the operator should stop the production and proceed to the exchange of knives

The average time of downtime for the change of knives is five minutes. After SMED analysis, it was possible to observe that the task is relatively simple and does not require a lot of tools. It was concluded that SMED analyses could not reduce the activity downtime. Instead, it was verified variability in the positioning of knives on the die: 30% of the operators placed the sharpened face against the die, while 70% placed the non-sharpened face against the die. Tests were conducted in order to optimize the working procedure that could aim for a longer knife preservation. It was concluded that, by positioning the non-sharpened against the die, the knives last longer. Thus, an OPL with the correct knives' positioning was made and directed to all operators.

3.5.4.3. Production line clearance

Due to the large number of PVC compounding references that Cabopol produces, the change of production is very common on a daily basis. Each change in production requires the cleaning of all equipments involved in the production line, so that the next production is not contaminated.

Firstly, the correct order for cleaning the line equipments was defined. Then, the correct time to clean the equipments was set and finally, the appropriate time to initiate a new formulation was designated (see Table 3).

Table 3 – Procedure to PVC production line cleaning and startup.

Equipment cleaning order	Clean:	After cleaning:
Mixer	After the last mixtures being transported to cooler hopper	
Cooler		
Cooler Hopper	After the last mixtures being transported to extruder silo	Activate the weighing of new reference raw materials
Extruder Silo	When the mixture cover only the force-feeding kneader	Start the transport of new reference mixtures to extruder silo
Extruder	Start purging the material when once initiated the extruder silo cleaning	
Granulator	Once extruder start purging material	
Granulate Drier		
Scale Bagging		Start the material extrusion of the new reference

The cleaning operations that require production interruption are the cleaning of granulator, the granulate drier and the scale bagging.

After the definition of equipment order cleaning, five scenarios that obligate the stoppage of production to clean the production line were defined (see Table 3).

SMED analysis involved the study of the operations that imply stoppage of production. These tasks were standardized through the creation of work instruction.

3.5.5. OEE calculation

Taking into account the high variability of the process limitations identified in Section 3.2, it was decided that OEE would be calculated at the end of each production line. Thus, taking into account the procedural context of the lines of PVC and the limitations involved, determining the OEE per line will encompass all bottlenecks present in the process, and through a detailed analysis of the individual indicators, it is possible to identify the largest yield loss points and consequently act on them.

The OEE per line translates thus a global indicator that represents a comprehensive view of all the losses and waste that undermines the performance of all equipment involved in the production line.

OEE is determined monthly, meeting the existing procedures for indicators monitored in Cabopol. Each OEE indicator is determined taking into account the following assumptions:

Availability index: measures productivity losses resulting from the downtimes of the production lines. This index considers not only unplanned stops but also planned stops, which could

contribute to the maintenance of focus. Simultaneously, it raises awareness for the fact that, although these planned stops cannot be eliminated, their time can be reduced using techniques such as the SMED. Availability index is calculated as follows:

$$\text{Availability} = \frac{\text{Effective production time (h)}}{\text{Planned production time (h)}}$$

Performance index: evaluates the productivity losses resulting from decreased production speed compared to the nominal value. The nominal production speed varies depending on the compound to be produced. The performance index of reference A is calculated as follows:

$$\text{Performance}_A = \frac{\text{Real debit}_A \left(\frac{\text{kg}}{\text{h}}\right)}{\text{Nominal debit}_A \left(\frac{\text{kg}}{\text{h}}\right)}$$

Then, the line production performance, in a given period of time, is calculated as follows:

$$\text{Performance} = \frac{\sum_i^n \text{Performance}_{Ai} \times \text{Produced quantity}}{\sum_i^n \text{Produced quantity}}$$

Quality index: measures productivity losses resulting from product production that does not meet the minimum requirements established for quality, including all grain produced out of specification and all the material from purging. It represents all the material that will not be valued at the price established for the finished product. Quality index is calculated as follows:

$$\text{Quality} = \frac{\text{Quantity of product in compliance (Ton)}}{\text{Quantity of RM that enters in the process (Ton)}}$$

4. Results and discussion

In this section, quantitative results from SMED and OEE analysis are presented.

4.1. Knives Exchange

The graph on Figure 8 registers knives life time over the months from January to March. The correct positioning of the knives was established by mid-February.

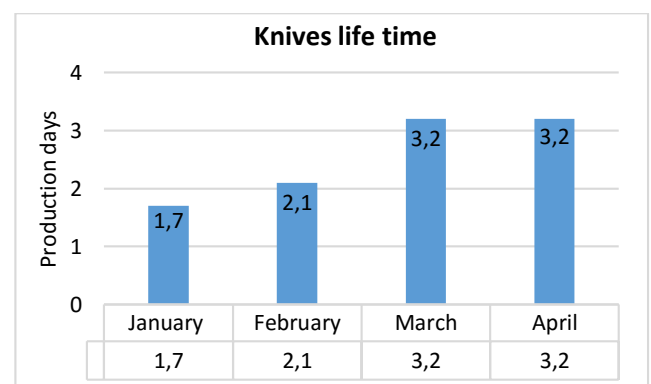


Figure 8 – Evolution of knives exchange life time.

By analyzing the data in Figure 8, it can be observed that the knives life time increased from 1,7 to 3,2 production days. February was the month of adaptation, when operators were trained in the created OPL. The respective knives life time increase is reflected in the reduction of knives change frequency,

as well as in the reduction of total downtime, which raises the availability for industrial production. The costs associated with knives acquisition decrease in the same proportion that knives change frequency decreases.

4.2. Production line cleaning

The graph on Figure 9 registers the PVC production line cleaning average time over the months from January to April.

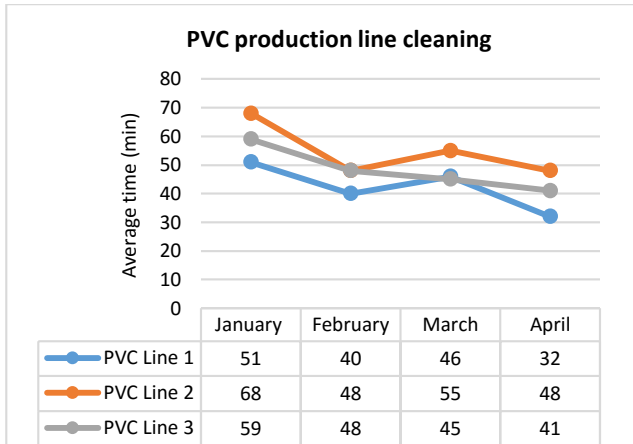


Figure 9 – Evolution of PVC line cleaning average time.

From the analysis of the data in Figure 8, it is possible to observe that the line cleaning average time is decreasing over the months. This proves the effectiveness of all procedures and work instructions created during the SMED analysis. However, it is expected that line cleaning average time stabilizes once all procedures and work instructions are consolidated and proper conducted.

4.3. OEE

The graph on Figure 10 registers the PVC production lines OEE and its indexes performance, quality and availability, over the months from January to April.

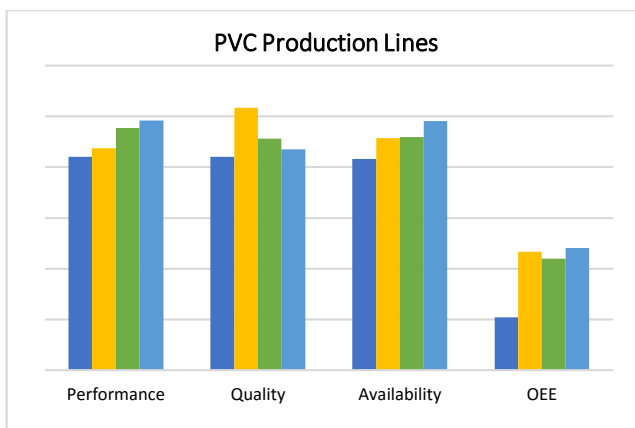


Figure 10 – Evolution of PVC production lines OEE.

By analyzing the data in Figure 10, it can be observed that the OEE value is raising over the months, which translates into a

positive indicator and proves the success of Lean techniques implemented.

For a further analysis in availability index, the graph on Figure 11 registers the PVC production lines downtime, over the months from January to April. These values are related to planned production time. The graph highlights the planned downtime and the unplanned downtime.

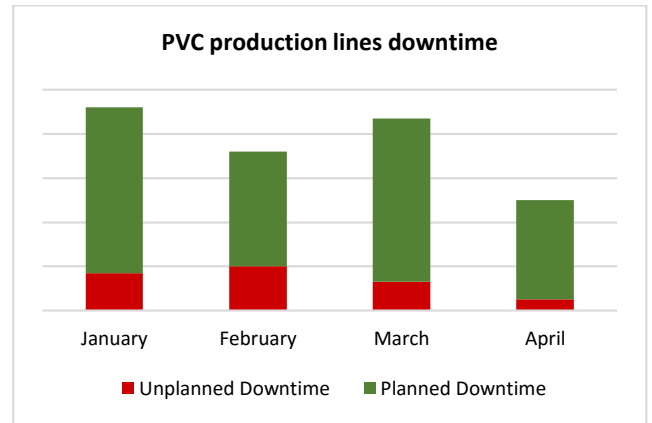


Figure 11 – Evolution of PVC production lines downtimes.

From the analysis of the data in Figure 11, it is possible to observe that there is a decreasing tendency for unplanned downtimes and planned downtimes. The origins of such results are not possible to quantify, however, it is believed that the autonomous maintenance program allowed the reduction in breakdowns (unplanned downtime), and 5S with SMED analysis allowed the reduction of planned downtimes.

To better allow the understanding of the relationship between OEE value and finished products sold, the graph on Figure 12 describes the evolution of such indicators over the months, from January to April.

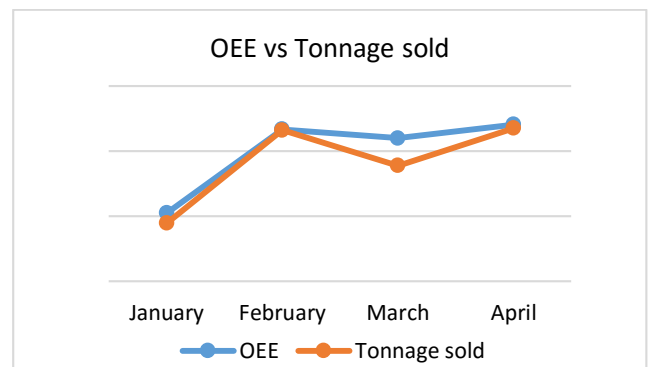


Figure 12 – Evolution of PVC production lines OEE vs tonnage sold.

The data presented on Figure 12 suggests that there is a similarity between the profile of OEE value and Tonnage sold. Such information supports the premise that OEE is a very viable indicator of the productivity levels of a process. This way, high OEE values translate into high quantity of sold finished products.

5. Conclusions

Iberian leader in the thermoplastics formulation, Cabopol - Polymer Compounds, SA plans to increase their productivity levels in order to, on one hand, to live up to the growing demand of the compounds that produce and, on the other hand, face the increasing markets competition existing nowadays.

The main objective of this study was the optimization of thermoplastic formulation in Cabopol - Polymer Compounds, S.A., using Lean Manufacturing techniques. Being a plant consisting with 14 production lines, this study only encompass the 3 PVC Lines of Cabopol 1.

The shop floor daily meetings proved to be an effective methodology for the detection of waste, making use of the experience of the operators and knowledge that, when coupled with the expertise of a multidisciplinary team, allows the establishment of effective actions in its elimination or reduction. Moreover, it was found that the introduction of a daily meeting triggered a high degree of motivation within the operators' mindset, in that their ideas and suggestions were heard and seen by top management, and in most cases, implemented.

The implementation of autonomous maintenance program instilled to employees a greater concern for the preservation of the equipment in which they operate. The TPM board has proved a very efficient way to pass information of nonconformity detected between production and maintenance. More, periodic inspections by operators enabled the detection of non-normal operating conditions at an early stage that if they had not been identified so readily, would probably evolve into more serious conditions that would force to stop machines.

Taking into account the results from the SMED analysis conducted, it was concluded that such technique can be useful on reduction downtimes and frequency of downtimes.

The introduction of OEE calculation in PVC production lines became very useful, mostly due to the fact that, before this experimental research, there were no indicators measuring the efficiency of Cabopol production processes. The value of OEE allowed an overview of the efficiency of processes and allowed the stratification of losses, allowing a subsequent elimination or reduction. The indicator supported the dynamics of continuous improvement, since it allowed the identification of opportunities that can bring further process improvements.

The Cabopol employees culture conversion into a continuous improvement culture, combined with Lean techniques implementations, instilled an increased awareness to waste identification and reduction, practiced everyday by everyone, that as a whole expedite the operations and allows to take full advantage of the production processes capacity, which translate into lower manufacturing costs and higher profit margins.

The raise on key performance indicators showed that the approach and methods implemented were effective, according to the improvements observed in the industrial results. Thus, also in Cabopol, Lean techniques are shown as an asset. In this sense, and taking into account the continuous improvement policy of Cabopol, we can conclude that the standardization of this work for all the production lines of the company is highly recommended.

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