SYSTEMS & MANAGEMENT
Electronic magazine

# LEAN MENTALITY: APPLICATION OF THE VALUE FLOW MAPPING IN THE PRODUCTIVE PROCESS OF A THERMOPLASTIC RECUPERATOR

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## ABSTRACT

Value Stream Mapping (VSM) is a tool considered as a starting point for lean manufacturing and it is responsible for identifying the various types of wastes existing in an organization and making visible the operations that add value to the product, providing the possibility of continuous improvements. This article aims to analyze the polypropylene manufacturing process in a thermoplastic recovery industry located in the south of Santa Catarina through the VSM, identifying the specific contributions generated by the tool, which show the different types of waste and improve the understanding of the whole process. The article was based on the case study method, based on bibliographical research. The results showed that the VFM indicated some changes and, with a relatively low investment in new equipment, will allow the reduction of the lead time of each ton produced, reduction of the cycle time in two sectors, reduction of the idle times of the operators, reduction of intermediate stocks, reduction in handling through forklifts and increase of the OEE index, bringing great advantages to the productive process.

**Keywords**: Lean Mentality; Value Stream Mapping; Waste.

PROPPI / LATEC
DOI: 10.20985/1980-5160.2019.v14n2.1533

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 211-222
DOI: 10.20985/1980-5160.2019.v14n2.1533

## 1. INTRODUCTION

In an extremely competitive and globalized world, finding ways to gain greater prominence and sustainability is something that constantly occupies the attention of organizations. With such competition, the waste from all stages of the production process has a significant impact on production cost and, therefore, its analysis has a great impact for future decision-making.

Companies rely on processes that happen in a chain; therefore, any and all failure will lead to possible initial or future losses. Lean Manufacturing has contributed to the visualization of these flaws with its philosophy, because it is a body of knowledge whose essence is the ability to eliminate wastes continuously and solve problems in a systematic way, thus meeting the needs of several companies, regardless of the organizational structure or market segment (Lean Institute Brazil, 2018).

The basis of the concept of lean thinking is the elimination of the various types of waste that exist in an organization. For Ohno (1988), the term waste refers to all elements of production that only increase costs without adding value, that is, activities that do not add value to the product, from the point of view of the customer, but are carried out within the production process.

The lean mentality brings along with it the Value Flow Mapping (VFM) that, according to Lee (2006), is a tool that provides a comprehensive view of the entire system, showing the interaction between the processes, which allows identifying the entire source or cause of waste with a simple tool, in which all steps involved are described visually.

With the elaboration of the VFM, a map is created, describing each stage of the process involved in the flow of materials and information in the value chain of a product. This map consists of a drawing of the current state, a drawing of the future state, and an implementation plan (Krajewski et al., 2009).

The use of VFM has become an efficient way of identifying waste in the process, since it allows a detailed study of the actions that add value and allows modifications in the ones that do not add, bringing positive results in terms of productivity and efficiency (Rother; Shook, 2003). Stock, rework, transportation, waiting and poor product quality are some of the wastes considered in the lean mentality, and the exploitation of each type brings the possibility of improvements not only in the productive sector, but in every organization. Thus, it is asked: what wastes are evidenced through the VFM in a process of recovery of polypropylene?

To answer this question, it was established as a general objective of this article: to analyze the manufacturing process of a thermoplastic recovery industry located in the south of Santa Catarina through the VFM. To achieve this goal, specific objectives are: (a) to map the production process through the VFM; (b) identify the waste of the process; and (c) propose actions for the reduction of waste found.

This research is justified by the specific contributions generated by the VFM tool, which show the different types of waste, improve the understanding of the entire process and provide possibilities for improvement. It adds to this the practical application of the acquired knowledge, amplifying them and adding value.

## 2. THEORETICAL REFERENCE

### Lean manufacturing

The Toyota Production System (TPS) is a production system developed by Toyota Motors Corporation, aiming to improve the manufacturing process in the face of the difficulties faced by Japan in the postwar period (Lima; Campos, 2014).

The STP gave rise to lean manufacturing (LM), which was defined by James P. Womack and Daniel T. Jones (1990) in their book "The Machine that Changed the World" (Brief Consultoria, 2014), in which the performance results obtained through the STP were demonstrated.

Chase et al. (2006) argue that the Toyota Production System aims to improve quality and productivity and is based on a culture of eliminating losses and respect for people, and for this to happen, Ballestero-Alvarez (2012) explains that the characteristics of the units required must be identified according to the requirements of the customer and then eliminate from the production line that which does not add value to the product but which consumes resources and damages its final result.

The LM has five basic principles that allow organizations greater flexibility and ability to meet customer needs (Womack, Jones, 1996 cited by Guimarães, 2014):

- Specify value: define what generates value from the customer perspective;
- Draw the flow of value from start to finish: identify all necessary actions and eliminate waste in the productive process;
- Create continuous flow: create flow without interruptions or waits;

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DOI: 10.20985/1980-5160.2019.v14n2.1533

- Use pulled production logic: produce according to demand;

- Seek perfection: apply continuous improvement in products and processes.

According to Dennis (2011), to achieve the ideals proposed by the LM philosophy, waste, overload and irregularity must be combated continuously. To implement LM, it is necessary to understand the structure and scope of production systems, defining which practices should be adopted. Envisioning the flow of information and materials throughout the company and having a broad view, not just of individual processes, is essential for the identification and disposal of waste.

## Waste in lean manufacturing

The basic principles of the LM philosophy are the concern with waste, which generates costs and does not add value to the product with an emphasis on continuous improvement and quality assurance at source, reduction of setups, better organization and layout of the workplace, level of stocks, respect for people, intense production, multifunction workers, standardization and simplification of operations, development of partnerships with suppliers, and preventive maintenance (Ghinato, 1995; Moreira, 2014; Lustosa et al, 2008).

Knowing that "waste can be defined as any activity that does not add value" (Slack et al., 2009), it can be said that eliminating waste or loss of production means eliminating activities that do not add value to the product; thus, waste can be characterized as any quantity greater than the minimum required of labor, raw material, equipment, components or any resources essential to production (Moura et al., 2012; Shingo, 1996).

According to Slack et al. (2002), "identifying waste is the first step in eliminating waste". Therefore, in order to achieve the consistent elimination of wastes proposed by the LM, an analysis is necessary in all the activities carried out in the factory, discarding or reducing all those that do not add value to the production (Corrêa; Corrêa, 2010).

For Ohno (1988), there are seven types of waste that need to be analyzed through LM in an organization. These wastes relate not only to the production line, but also to the increase in product volume, sequencing of orders and administrative activities (Liker, 2005).

- Inventory: consists of excess stock of raw material, processed product and finished product. This entails higher costs, occupation of larger areas, inventory maintenance time and obsolescence;

- Processing: waste related to the lack of efficiency of production, by performing activities that do not add value to the product;

- Defects: consist of the processing of defective products and wasted materials used in addition to rework operations. The main causes are: unskilled labor for the activity, lack of standardization and control of the process, disqualified suppliers and communication between company and customer fault;

- Movement: it includes the unnecessary movements carried out by the workers during the execution of their labor activity, such as searching, walking, flexing, lifting and lowering. The reduction of this waste occurs through simplification of work, changes in layout, organization of the environment and standardization of activities;

- Overproduction: means anticipating demand, producing more than necessary for the next production process;

- Waiting: idleness of people and equipment. Resources are required to wait unnecessarily, waiting for the availability of others. It also occurs when workers are busy producing in-process inventory that is not needed immediately;

- Transportation: consists of the unnecessary movement of raw material, tools and equipment in the company. You can eliminate it by making changes to the physical arrangement and organization of the desktop.

To achieve the elimination or reduction of these wastes, the LM has some tools and techniques, among which Liker (2005) presents the VFM as a great tool to start an LM.

## Value Stream Mapping

The value stream comprises everything that is accomplished from the raw material obtained until the delivery of the product to the final customer. In analyzing the value flow of an organization, it is important to identify and separate processes that actually result in value to the customer from those who do not provide value. In this way, processes that generate value must be maximized, while others must be minimized; however, those that do not generate value and are still unnecessary should be eliminated (Albertin; Pontes, 2016; Lage Jr., 2016).

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Marodin and Saurin (2013) identified the VFM as one of the most used techniques for the implementation of the LM, presenting the increase of productivity and the reduction of lead time as typical results. For Jasti and Sharma (2014), VFM is an important technique that helps managers understand current operating conditions and identify opportunities for improved performance.

The value flow mapping initially has the function of identifying the process time in each productive cell, the space traveled, manufacturing difficulties, and wastes of time and material. It should be noted that the analysis of these aspects must be done as accurately as possible with reality, in order to present the true situation (Rother; Shook, 2003).

For the execution of Value Stream Mapping, it is suggested to choose a single product and follow the flow of production from the supplier of the raw material to the consumer, carefully representing the map of the current state of its material and information flows (Erlach, 2013). Soon afterwards, the map of the future state is designed to contemplate opportunities for improvement and to represent how the materials and information should flow (Elias et al., 2011). The value stream mapping generates a map of the manufacturing process and for this it generates some metrics such as cycle times, lead times, setup times, inventories, as well as production and information flow throughout the process (Sparks, 2014).

Keyte and Locher (2004) state that the metrics in a value stream are used to assist in the visualization of processes and their wastes. They are useful in a number of cases, but do not represent all situations. In some cases, to better define the company process, it is necessary to develop specific indicators.

Sharma et al. (2006) suggest OEE – Overall Equipment Effectiveness – as a specific indicator for being a powerful tool to measure and analyze the performance of equipment in a productive process, through a detailed analysis of its efficiency. The index becomes possible by multiplying three factors: availability x performance x quality, where:

- Availability - produced time/scheduled time;
- Performance - actual production/theoretical production;
- Quality - quantity of products without defects/quantity produced.

In addition to eliminating waste and optimizing the flow of the manufacturing process, the VFM allows for a number of other benefits that facilitate real control of the production process in the company. These advantages are: (1) More efficient processes; (2) Reduction of time involved in processes; (3) More satisfied professionals; (4) Quality improvement; (5) Products/services best suited to consumer needs; (6) More reliable systems; and (7) Cost Reduction (Shiver; Etiel, 2010; Aherne; Whelton, 2010). Finally, Costa and Jungles (2006) argue that the objective of mapping the current state is to identify the sources of waste and eliminate them by implementing a flow of value into a "future state" that can become a reality in a short period of time.

According to Biagio (2015) and Lage Jr. (2016), the designs for Value Stream Mapping can be done both computationally and manually, following their own symbology with items that represent processes, external sources, information boxes, stocks, deliveries, pushed or pulled drives, operators, among other factors present in a production flow. Therefore, the VFM shows itself as easy to understand and apply due to the simplicity surrounding its methodology, proving that it is an important tool for process improvement with the implementation of LM.

## 3. METHODS

In the preparation of this article, bibliographical research was initially used, since its most common objectives are to understand and discuss the literature review on the research topic (Tachizawa and Mendes, 2006), acquiring theoretical background on the subject.

As far as the research method is concerned, because it is an intense investigation of the process in its current context, a case study was adopted, allowing a better understanding of contemporary real events (Miguel, 2007), gathering detailed information and systematic information about a phenomenon (Patton, 2002).

Data collection was carried out through multiple sources of research in a natural environment (Creswell, 2010). During the month of September 2018, daily visits were made *in loco*, in order to know and analyze the current process through direct observation. Four informal interviews with employees were carried out, aiming at raising the main critical factors of the process and the use of files and reports related to production, allowing the analysis of different data (Gibbs and Costa, 2009), enabling the structuring of the following metrics used in VFM: cycle time, changeover time, processing time, lead time, and OEE.

The data analysis follows a structure of waste identification. According to Slack et al. (2008), a waste can be defined as any activity that does not add value to the product.

The procedures adopted to implement the VFM followed steps suggested by Rother and Shook (2003), starting

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with the selection of a product family, construction of the map in its current state and construction of the map in a future state.

### Company characterization

The present research was carried out in an industry in the segment of recovery and recycling of thermoplastics located in the city of São Ludgero/SC, founded in 2005, which brings the correct environmental solution for several types of plastics, reusing industrial shavings that, after the manufacture, are transformed into raw material (granulated) for the manufacture of other products, such as: buckets, bags and roof tiles.

The company *Alfa* (fictitious name) currently has a production capacity of 950 tons/month, divided into basically three finished products: recovered polypropylene, recovered low density polyethylene and recycling of various materials for the manufacture of ecological tiles, with its main clients in the South and Southeast regions.

The organization runs every day, in a continuous and uninterrupted production system, divided into three shifts, generating eighty-five direct jobs and several other indirect ones, such as mechanics, truck drivers, electricians and other outsourced professionals, as well as smaller recycling companies that assist in the manufacture of the agglutinated by-product.

## 4. RESULTS AND DISCUSSIONS

During the visits, points were observed that interfere in a better efficiency in the process, considered in the LM as waste, such as: intermediate stock between processes, resulting in a high lead time index for each ton produced, excessive handling of forklifts transporting products, high cost with outsourcing and lack of raw material between processes, causing the process to have an unplanned downtime.

To minimize and even eliminate these wastes, Value Stream Mapping was performed, describing the entire recovery process of Polypropylene (PP), from the entry of chips to the exit of the grains, which are stored in big bags with a capacity of one ton. Due to the large volume of production, the metric unit was used in tons and the OEE index was added to the production mapping data box to evaluate the efficiency of the process.

The activities belonging to the recovery process of the PP follow the steps described in figure 1:

The process begins with the purchase of industrial shavings, which are traded in several companies nationwide, with a constant variation in price and quality of the material.

Chippings arrive in chartered trucks from Monday to Friday during business hours. After arriving at the company, the trucks are directed to the first stage in the weighing sector, where the total weight, the quality of the material, the quantity of water and what types of thermoplastics are in the load are verified, always with accompaniment of the person in charge of the purchase. The trucks are then unloaded with forklifts, at a cycle time of 10 min/ton with a 73% OEE index and are deposited at the first intermediate stock point that precedes the separation step, with an average waiting time of 3,060 minutes.

In the second stage of value aggregation, in the separation sector that operates during business hours, the chips are placed on mats, where operators manually separate them and remove different types of plastics that are pressed into bales and separate them according to the type and color, with a cycle time of 17 min/ton and 62% OEE. With the PP shavings baled and separated, approximately 30% of the daily production is destined to a company outsourced for the agglutination; the remainder is sent to the separate shavings' storage with a holding time of 6,370 minutes.

The third stage occurs in the agglutination sector. With the production of two agglutinators divided into three shifts, the shavings undergo a process that removes the paint from the material by friction and turns it into a farinaceous species, with a cycle time of 91 min/ton and OEE of 59%. The agglutinated material is stored in big bags and is sent to the bonded material deposit, with a waiting time of 1,068 min/ton.

In the last stage of value aggregation, the agglutinated material is sent to a mixer silo and then extruded into PP grains and automatically packaged into one-ton capacity big bags at a cycle time of 89 min/ton and OEE of 76%. Finally, the big bags are sent to the warehouse, ready to be picked up by the shipment as soon as the customer needs it. The current state map was presented with the help of the Microsoft Office Excel computational tool, as follows:

At the end of the Current Value Flow Mapping, meetings were held among employees, presenting the wastes evidenced through the VFM, with the purpose of receiving instructions and ideas that would assist in the development of the future VFM.

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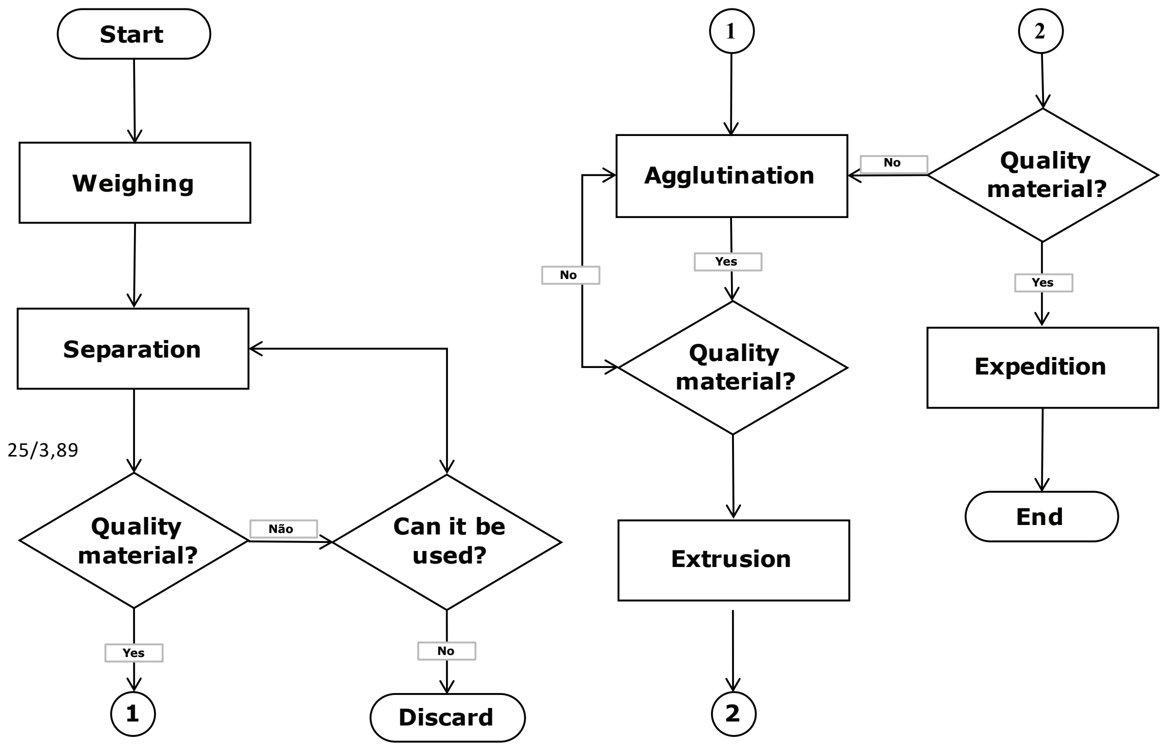


**Figure 1**. Flowchart of the productive process

Source: The authors themselves

**Table 1**. Waste Found

| WASTE | Wei-ghing | Separa-tion | Aggluti-nation | Extru-sion |
|---|---|---|---|---|
| Stock | | X | X | |
| Processing | X | X | X | X |
| Defect | | | | X |
| Movement | X | X | X | X |
| Overproduction | | | X | |
| Wait | X | X | X | X |
| Transport | X | X | X | X |

Source: The authors themselves

Table 1 shows the wastes found in the PP manufacturing process, the waste of stock, which consists of the excess of raw material in process or finished product found in the separation and agglutination sectors.

Lack of production efficiency is termed as waste processing. The movement that includes unnecessary movements by employees, the waiting that consists in the idleness of people and equipment, and the transportation, which is the unnecessary movement of raw material, were evidenced in all sectors of the company.

With regard to waste called defect, which basically deals with the quality and rework of the products, it was found only in the extrusion sector.

The overproduction waste found in the agglutination sector was also demonstrated in the Table above, since it was directed by the organization to the total elimination, because it is a material that is stored in big bags with incidence of fire propagation, thus being an extremely hazardous material.

## Improvement proposals

The recommendation for the first improvement point is the elimination of the intermediate stock prior to the separation, causing the shavings to be discharged directly onto the separation mats, reducing waste by moving forklifts and reducing lead time. The verification of the material passes to

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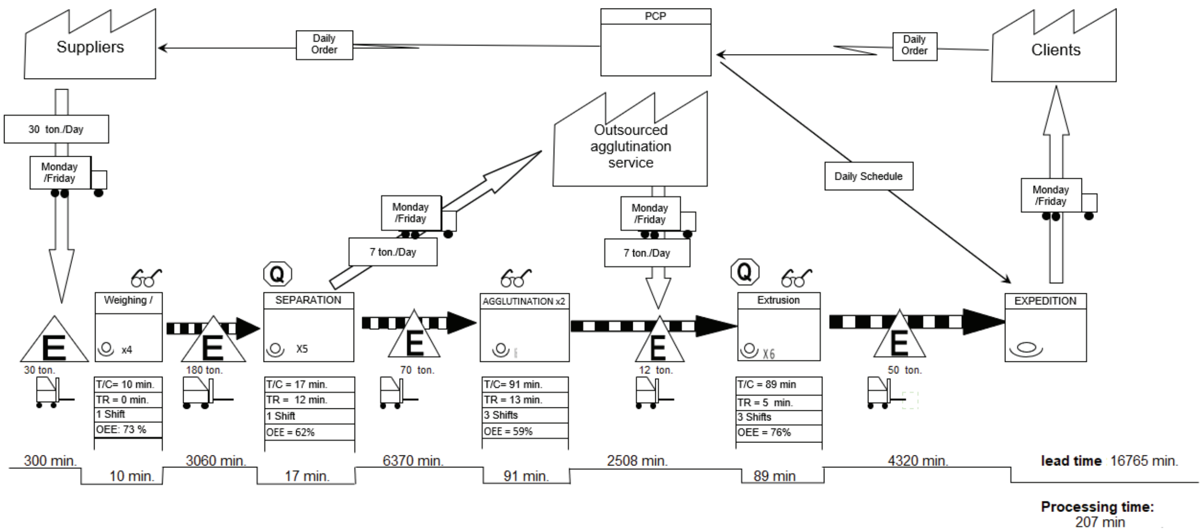


**Figure 2**. Current Value Stream Mapping
Source: The authors themselves

the responsibility of the separation sector and, with this, the cycle time decreases and the OEE index is increased.

With the chips being deposited directly on the mats, it is expected to eliminate the waiting time caused daily due to lack of material, rework and excessive movement, increasing the OEE index and the processing capacity. In a joint decision with those responsible, claiming a better quality in the shaving mixture, it was decided to maintain and increase the stock of separate shavings.

It is also suggested the acquisition of a new agglutination equipment, leading the company to have all manufacturing processes internally, maintaining an efficient quality control, reducing the lead time and increasing its productive capacity, since the bottleneck is in this sector. Still in the agglutination sector, the proposal is to reduce downtime due to lack of materials and the change in the process of changing the razors, since before they were sharpened by the operators themselves, wasting their productive time, and now they will be sharpened by the maintenance sector, thus reducing the time of these exchanges from 240 min to 90 min a day. This means a daily gain of 150 minutes. With this measure, it is expected the increase in the production volume, the decrease of the cycle time and the improvement in the OEE index.

In view of the visits made in the company, it was found that the speed of the extruder was often decreased due to lack of bonded material. With the modifications made in the agglutination sector, the expectation is that there will be no more stops due to lack of material, keeping the extruder always at maximum speed.

The improvements expected to be achieved with the changes are: lead time decrease for each ton of polypropylene produced, increase of efficiency by OEE indicator, reduction of outsourced costs, reduction of transportation by means of forklifts, and decreased cycle time of the agglutinated sector.

The proposed flow to the company remains the same, with a system pushed by management option, but with some improvements suggested through the VFM, excluding the outsourcing of the agglutinated material and some intermediate stocks, together with the increase of availability in all sectors, bringing an improvement in the OEE index.

At the end of the design of the future state mapping, some improvements were observed with the proposed changes, and a data table of the process was elaborated, comparing the current process with the proposed one. Lead time is the time from the moment of the customer's order to the arrival of the product to it, including the times in which value is added to the product and the times when the raw material gets stuck in inventory or waiting for the next step.

**Table 2**. *Lead Time of Activities*

| Activities | Current State | Future State |
|---|---|---|
| Receiving | 300 min | 300 min |
| Weighing | 3060 min | 0 min |
| Separation | 6370 min | 6100 min |
| Agglutination | 2508 min | 0 min |
| Extrusion | 4320 min | 4320 min |
| Total processing time | 207 min | 175 min |
| Lead Time | 16765 min | 10895 min |

Source: The authors themselves

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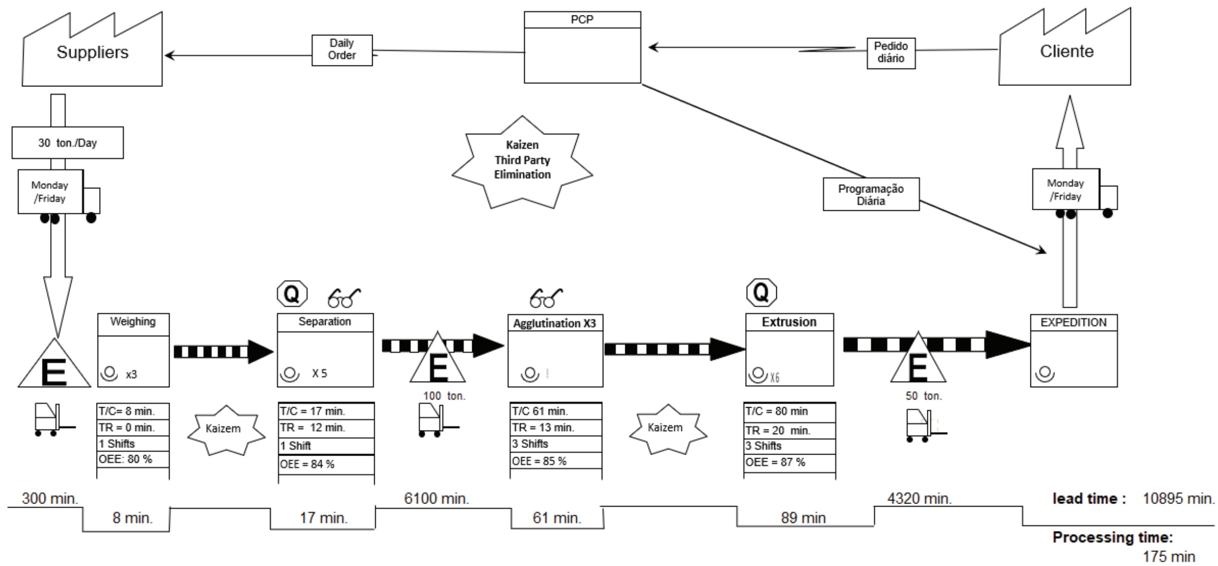


**Figure 3**. Future Value Flow Mapping

Source: The authors themselves

With the elaboration of Value Stream Mapping in the future state, it is observed that in Table 2, there is a lead time reduction of 34%. This reduction is explained by the change in the receipt of the chips, eliminating the rework and the intermediate stocks between reception, weighing, separation and the installation of agglutination machinery. With the change, it will be necessary to hire two new employees to perform the function of agglutinator operator; a collaborator of the weighing sector will be transferred to the agglutination sector to compose the new staff.

**Table 3. Processing time**

| Activities | Current State | Future State |
|---|---|---|
| Weighing | 10 min | 8 min |
| Separation | 17 min | 17 min |
| Agglutination | 91 min | 61 min |
| Extrusion | 89 min | 89 min |
| Processing time | 207 min | 175 min |

Source: The authors themselves

The cycle time is defined from the moment an operation starts until the moment the operation is completed; in the sum of all cycle times, the processing time, which is the time of manufacture of a product, is obtained. With the proposal for improvements evidenced through the VFM, the cycle time in the weighing and agglutination sectors has improved. With the responsibility of checking the material being carried out by the separation sector, there was a decrease in the cycle time of the weighing sector, without affecting the cycle time of the separation, thus leading to a productivity gain. In the agglutination sector, there was an investment of R$ 70,000.00 for the installation of the new machine with a payback of approximately three months. This led to a 15.4% improvement in processing time, with a production volume gain of one ton per day.

**Table 4**. Overall Equipment Effectiveness

| Activities | Current State | Future State |
|---|---|---|
| Weighing | 73 % | 80 % |
| Separation | 62 % | 84 % |
| Agglutination | 59 % | 85 % |
| Extrusion | 76 % | 89 % |
| Average OEE | 68 % | 85 % |

Source: The authors themselves

The overall efficiency of each sector was measured through the OEE index, which allows verifying points of waste from the analysis of three points: availability, performance and quality. The significant increase of 17% in the average was due to the restructuring in the system of supply of shavings, making the leaders of each sector responsible for this process at no additional cost, increasing the availability and the performance, and consequently, increasing production volume.

## 5. CONCLUSION

The proposal of the VFM is to clearly indicate the sources of waste from the production processes, through a critical

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analysis of the most important points, providing opportunities for improvement.

This article presented the analysis of the polypropylene recovery process in a thermoplastic recovery company, located in the south of Santa Catarina, through Value Stream Mapping, identifying the wastes in the manufacture, in search of improvement in the efficiency of the process and presenting suggestions for improvements.

The wastes found were: stockpiles in the separation and agglutination sector, waste from defects in the extrusion industry, overproduction waste in the agglutination and processing waste, handling, and waiting and transportation sectors in all sectors.

The VFM indicated that some changes and relatively low investment in new equipment provided significant changes in the rates of each ton produced, leading to lead time reduction, reduced cycle time in the weighing and agglutination sectors, reduction of intermediate stocks, reduction in handling through forklifts and increase of the OEE index, which brought great advantages in the volume of production.

In addition, through Value Stream Mapping, it became possible to visualize the various types of waste, allowing them to engage directly at crucial points, making efforts to be used in an insightful way at each stage of the process and reaching the expected results.

The VFM is a bootstrap tool for Lean Manufacturing; therefore, for the expansion of lean thinking to extend to all sectors of the organization, it is necessary that all those involved commit themselves to the objectives, causing a transformation in the organizational culture, differentiating it with the market, responding positively to their expectations.

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APPENDIX A. Analysis of times to obtain OEE in the weighing sector

**Current state weighing**

| Metrics | Activities | Times |
|---|---|---|
| Cycle time per ton | | 10 min |
| Daily workload | | 480 min |
| Scheduled Stops | Coffee | 20 min |
| | Restroom | 20 min |
| **Total time scheduled** | | **440 min** |

| Metrics | Activities | Times |
|---|---|---|
| Unscheduled stops | Missing material | 20 min |
| | Waiting for instructions | 15 min |
| | Idle Time | 30 min |
| **Total time producing** | | **375 min** |

| | | | |
|---|---|---|---|
| **Availability** | Time Producing / Scheduled time | 375 Kg / 440 Kg | **85%** |
| **Performance** | Actual production / Theoretical production | 37500 Kg / 44000 Kg | **85%** |
| **Quality** | Good / Produced | 45000 Kg / 45000 Kg | **100%** |
| **OEE** | **73%** | | |

**Future state weighing**

| Metrics | Activities | Times |
|---|---|---|
| Cycle time per ton | | 8 min |
| Daily workload | | 480 min |
| Scheduled Stops | Coffee | 20 min |
| | Restroom | 20 min |
| **Total time scheduled** | | **440 min** |

| Metrics | Activities | Times |
|---|---|---|
| Unscheduled stops | Missing material | 0 min |
| | Waiting for instructions | 15 min |
| | Idle Time | 30 min |
| **Total time producing** | | **395 min** |

| | | | |
|---|---|---|---|
| **Availability** | Time Producing / Scheduled time | 395 Kg / 440 Kg | **90%** |
| **Performance** | Actual production / Theoretical production | 49375 Kg / 55000 Kg | **90%** |
| **Quality** | Good / Produced | 49375 Kg / 49375 Kg | **100%** |
| **OEE** | **81%** | | |

Source: The authors themselves

**Electronic Journal of Management & System**
Volume 11, Number 2, 2019, pp. 211-222
DOI: 10.20985/1980-5160.2019.v14n2.1533

APPENDIX B. Analysis of times to obtain OEE in the separation sector

**Current state separation**

| Metrics | Activities | Times |
|---|---|---|
| Cycle time per ton | | 17 min |
| Daily workload | | 480 min |
| Scheduled Stops | Setup | 30 min |
| | Restroom | 20 min |
| **Total time scheduled** | | **430 min** |

| Metrics | Activities | Times |
|---|---|---|
| Unscheduled stops | Missing material | 80 min |
| | Others | 12 min |
| **Total time producing** | | **338 min** |

| | | | |
|---|---|---|---|
| **Availability** | Time Producing / Scheduled time | 338 Kg / 430 Kg | **79%** |
| **Performance** | Actual production / Theoretical production | 19882 Kg / 25204 Kg | **79%** |
| **Quality** | Good / Produced | 19882 Kg / 19882 Kg | **100%** |
| **OEE** | **62%** | | |

**Future state separation**

| Metrics | Activities | Times |
|---|---|---|
| Cycle time per ton | | 17 min |
| Daily workload | | 480 min |
| Scheduled Stops | Coffee | 30 min |
| | Restroom | 20 min |
| **Total time scheduled** | | **430 min** |

| Metrics | Activities | Times |
|---|---|---|
| Unscheduled stops | Missing material | 25 min |
| | Waiting for instructions | 12 min |
| **Total time producing** | | **393 min** |

| | | | |
|---|---|---|---|
| **Availability** | Time Producing / Scheduled time | 393 Kg / 430 Kg | **91%** |
| **Performance** | Actual production / Theoretical production | 23118 Kg / 25294 Kg | **91%** |
| **Quality** | Good / Produced | 23118 Kg / 23118 Kg | **100%** |
| **OEE** | **84%** | | |

Source: The authors themselves

APPENDIX C.- Analysis of times to obtain OEE in the agglutination sector

**2 Current state agglutinators**

| Metrics | Activities | Times |
|---|---|---|
| Cycle time per ton | | 91 min |
| Daily workload | | 1440 min |
| | Changing of razors | 120 min |
| Scheduled Stops | Bathroom | 20 min |
| | Interval | 180 min |
| **Total time scheduled** | | **1120 min** |

| Metrics | Activities | Times |
|---|---|---|
| | Sharpen razors | 150 min |
| Unscheduled stops | Missing material | 70 min |
| | Change of shift | 50 |
| **Total time producing** | | **850** |

| | | | |
|---|---|---|---|
| **Availability** | Time Producing / Scheduled time | 850 Kg / 1120 Kg | **76%** |
| **Performance** | Actual production / Theoretical production | 9341 Kg / 12308 Kg | **76%** |
| **Quality** | Good / Produced | 9341 / 9341 | **100%** |
| **OEE** | **58%** | | |

**2 Future state agglutinators**

| Metrics | Activities | Times |
|---|---|---|
| Cycle time per ton | | 61 min |
| Daily workload | | 1440 min |
| | Changing of razors | 120 min |
| Scheduled Stops | Bathroom | 20 min |
| | Interval | 180 min |
| **Total time scheduled** | | **1120 min** |

| Metrics | Activities | Times |
|---|---|---|
| | Sharpen razors | 0 min |
| Unscheduled stops | Missing material | 35 min |
| | Change of shift | 50 |
| **Total time producing** | | **1035** |

| | | | |
|---|---|---|---|
| **Availability** | Time Producing / Scheduled time | 1035 Kg / 1120 Kg | **92%** |
| **Performance** | Actual production / Theoretical production | 16967 Kg / 18361 Kg | **92%** |
| **Quality** | Good / Produced | 16967 / 16967 | **100%** |
| **OEE** | **85%** | | |

Source: The authors themselves

**Electronic Journal of Management & System**
Volume 11, Number 2, 2019, pp. 211-222
DOI: 10.20985/1980-5160.2019.v14n2.1533

APPENDIX D. Analysis of the times to obtain OEE in the extrusion sector

**Extruder current status**

| **Metrics** | **Activities** | **Times** |
|---|---|---|
| Cycle time per ton | | 89 min |
| Daily workload | | 1440 min |
| Scheduled Stops | Matrix exchange | 25 min |
| | Restroom | 20 min |
| **Total time scheduled** | | **1395 min** |

| **Metrics** | **Activities** | **Times** |
|---|---|---|
| Unscheduled stops | Granulator | 15 min |
| | Lack of material | 65 min |
| **Total time producing** | | **1315 min** |

| | | | |
|---|---|---|---|
| **Availability** | Time Producing | 1315 Kg | **94%** |
| | Scheduled time | 1395 Kg | |
| **Performance** | Actual production | 14775 Kg | **82%** |
| | Theoretical production | 18000 Kg | |
| **Quality** | Good | 14800 Kg | **99%** |
| | Produced | 15000 Kg | |
| **OEE** | **76%** | | |

**Extruder future state**

| **Metrics** | **Activities** | **Times** |
|---|---|---|
| Cycle time per ton | | 89 min |
| Daily workload | | 1440 min |
| Scheduled Stops | Changing of razors | 25 min |
| | Restroom | 20 min |
| **Total time scheduled** | | **1395 min** |

| **Metrics** | **Activities** | **Times** |
|---|---|---|
| Unscheduled stops | Granulator | 0 min |
| | Lack of material | 0 min |
| **Total time producing** | | **1395 min** |

| | | | |
|---|---|---|---|
| **Availability** | Time Producing | 1395 Kg | **100%** |
| | Scheduled time | 1395 Kg | |
| **Performance** | Actual production | 15674 Kg | **87%** |
| | Theoretical production | 18000 Kg | |
| **Quality** | Good | 15674 Kg | **100%** |
| | Produced | 15674 Kg | |
| **OEE** | **87%** | | |

Source: The authors themselves

APPENDIX E. Cost analysis for acquiring an agglutinator

| **Cost per kg agglutinated** | **Value kg** | **Monthly** | **Annual** |
|---|---|---|---|
| Cost with Outsourcing | R$ 0,42 | R$ 88.200,00 | R$ 1.058.400,00 |
| Cost in the company | R$ 0,25 | R$ 52.500,00 | R$ 630.000,00 |
| **Difference** | **R$ 0,17** | **R$ 35.700,00** | **R$ 428.400,00** |

| | |
|---|---|
| **Complete agglutinator cost** | **R$ 70.000,00** |
| **Return** | **2 months** |

**Received:** May 2, 2019

**Approved:** May 15, 2019

**DOI:** 10.20985/1980-5160.2019.v14n2.1533

**How to cite:** Pinto, N. M.; Luiz, F. A.; Moreira, F. K. (2019), "Lean mentality: application of the value flow mapping in the productive process of a thermoplastic recuperator", Sistemas & Gestão, Vol. 14, No. 2, pp. 211-222, available from: http://www.revistasg.uff.br/index.php/sg/article/view/1533 (access day abbreviated month year).