Application of Value Stream Mapping in Mold Copper Coils for Energy Generators

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Abstract. The product development process is becoming increasingly critical to the competitiveness of industries due to the growing internationalization of markets and the increase in the diversity and variety of products. Industries are increasingly looking for methods and tools to help locate waste and take action to eliminate it. This article aims to deal with concepts and presentations of the applicability of the VSM (Value Stream Mapping) tool on a production line that produces copper molded coils to order, manufactured for the stators of medium and high voltage hydroelectric power station generators. Using a case study methodology applied in an industry in the southwestern region of Paraná (Brazil), with the tool's competence in implementing the principles of lean production in operations, it showed that making maps of the current and future state in the language standardized by the Lean philosophy can be applied in the development process of this product. After analyzing the maps and the spaghetti diagram, it was possible to identify points of waste and operations that do not add value. Among the most important results were better visual management, a 20% reduction in lead time, elimination of bottlenecks, intermediate stocks and optimization of the production process.

Keywords: VSM, Sustainable operations, Operations Strategy, hydroelectric Generators, continuous improvement.

1 Introduction

The expansion of world trade and the evolution of production processes in recent decades have created a constantly changing environment for industries. Technological innovations, continuous improvement in search of higher quality, reductions in waste and costs and adaptation to the various markets are essential requirements for industries to remain competitive.

In Brazil, the hydroelectric sector is very important, since 73.6% of electricity comes from hydroelectric plants [1]. With its great hydroelectric potential (many plateau rivers), the country makes use of its favorable geography for the production of electricity, and water is a renewable source that contributes to this form of energy being widely used as an energy matrix that has consolidated technologies for harnessing it [3]. However, the process of producing components [1] for hydroelectric power plants needs to be adapted for each new project, due to the fact that the plants are unique since the design solutions for hydroelectric power plants are unique, specific to each case, with equipment that alters the size, power, voltage and rotation for each case of the plant, to characterize the manufacture of equipment as custom production or non-serial production.

Considering the importance of the segment, this article aims to understand some of the factors that influence decision-making, the continuous improvement process and the management of the production of molded copper coils for hydro generators using knowledge from Lean manufacturing through the VSM tool. According to [10], VSM is a tool that performs a qualitative analysis aimed at improving resources and avoiding waste. According to [4], VSM is "a tool capable of looking at value-adding processes horizontally". It aims to analyze all processes in order to locate possible deviations and eliminate waste.

A hydroelectric plant can be defined as a set of works and equipment whose purpose is to generate electricity by harnessing the hydraulic potential of a river. Hydraulic potential is provided by the hydraulic flow and the concentration of gradients along the course of a river [14]. One of the main elements of a hydroelectric power station are the generators, which are coupled to a hydraulic turbine and connected to the power grid. The principle of how a generator works is based on the phenomena of electromagnetic induction to which a conductor or a coil is subjected when it undergoes a variation in magnetic flux [6].

The generator is divided into two large parts, the rotor (moving part) and the stator (fixed part). The rotor, which houses the field winding, rotates inside the stator and creates the variable magnetic field needed to induce voltage in the stator. The shaped coils are part of the stator assembly, where the alternating currents are generated when the rotor rotates. These coils are part of the armature winding and are used for higher voltage classes, equal to or above 2,200V. Molded copper coils are made up of rectangular copper wire with a layer of polygrass (fiberglass), layers of mica tape and impregnated with a special resin. On average, a medium-power generator has 150 molded coils per generator, as shown in figure 1. Generators with a voltage of less than 2,200V are made with coils of enameled copper wire according to the AWG standard. The importance of the study for the practical area is to standardize the manufacture of coils, which directly influence performance and electricity generation, with support for the pillars of sustainability in increasing product quality and reducing manufacturing lead time, and subsequent maintenance or replacement of coils when already installed in generators at hydroelectric plants.

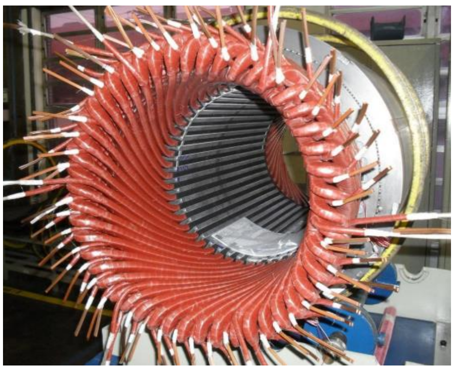

Fig. 1.: Example of a coiled stator
Source: Martins (2010)

2 Literature review

2.1 Lean Manufacturing

The Lean philosophy provides a set of tools and concepts aimed at identifying and eliminating waste in production processes, while focusing on customer needs.

Industry 4.0 has begun to advance production with autonomous and flexible systems, thus revolutionizing production processes. It is known that the holistic integration of Lean Manufacturing (LM) tools, such as Just in Time (JIT), Kan-ban, Poka-Yoke, Value Stream Mapping (VSM), Kaizen and Toyota Productive Main-tenance (TPM), with digital technologies, such as Big Data, Cloud Computing, Augmented Reality (AR), Virtual Reality (VR), Virtual Simulation (VS) Artificial Intelligence (AI) and Internet of Things (IOT), developed by Industry 4. 0 offers companies a series of organizational gains, such as agility in the production process and product quality assurance throughout its manufacturing stages [13]. In addition, it is known that Industry 4.0's contribution to creating more sustainable industrial value will be remarkable in the future.

In the literature, this contribution is attributed to the economic, environmental and social dimensions of sustainability, since the implementation of lean manufacturing in smart manufacturing environments is advantageous for reducing costs. Therefore, the implementation of Industry 4.0 is identified as a cost-intensive operation, considering the investment required and the perceived benefits [4].

The study presented by [11] sets out the principles of Lean Manufacturing. These principles serve as a basis to guide the adoption, implementation and development of lean manufacturing. The first, the value principle, is considered to be the essential starting point for acquiring the lean mentality. Value is added for the customer during the process through various activities. The second principle refers to the flow of value, in which it is essential to develop an organizational mechanism aimed at creating a value chain by visualizing the entire process and eliminating waste completely. The third principle is continuous flow, which makes it possible to visually represent all the stages involved, both materials and information, from the supplier to the consumer. The fourth principle is the pull system. Pull production is a process in which the production of a good or service should not begin until the customer has requested it. The fifth and final principle is the perfection principle. It arises from the idea that the company should have the skills to specify value accurately, identify the value chain as a whole and have the competence to develop steps that flow continuously and flexibly.

Presented by [8] the seven wastes of the Toyota Production System (STP) that must be eliminated:

- Overproduction: Making more than the quantity needed. According to Toyota, this is the biggest waste, as it leads to all the others;
- Stock (Inventory): Material held in stock, resulting in wasted space and investment in maintenance;
- Transportation: Unnecessary movement of materials and information, wasting time and resources;
- Waiting: People waiting or waiting for materials to be processed;
- Unnecessary processing: Unnecessary steps from the customer's point of view; activities that do not transform the product;
- Defect: Defective products, customer complaints, rework, returns;
- Handling: Unnecessary or slow handling.

2.2 Value Stream Mapping

Of the main waste elimination techniques proposed by this management philosophy, one stands out: Value Stream Mapping (VSM). This tool was proposed by [10] and is based on Value Stream Analysis.

The VSM or value stream map is used as a communication and planning tool [10], as well as helping employees to get to know their processes in detail. It establishes a common language between employees and subsequently initiates an improvement process.

According to [10], it is a methodology for seeing the entire flow of information and material, allowing organizations to visualize and identify their waste streams or activities that don't add value, and to direct their actions towards the search for better flow performance.

According to [12], the methodology developed is highly advantageous for industries, as it makes it possible to achieve sustainable organizational systems with minimal waste on the shop floor, thus achieving the goal of Industry 4.0.

The VSM represents the entire supply chain and involves the process as a whole, from raw materials to the finished product. Its focus is on eliminating waste, reducing lead times and identifying bottlenecks. The tool presents the company's current situation, allowing it to see possible improvements to the process [5].

For [6], the material flow represents the movement of materials within the factory, while the information flow tells each process what to manufacture and the sequence of work. Although the material flow is much more visible and therefore more addressed by improvement programs, the information flow must be treated with the same importance for lean production.

The VSM tool makes it possible to connect all the processes that make up the production flow, from the supplier to the end consumer [10], identifying all the stages in order to apply lean thinking techniques. According to the authors, value stream mapping should follow the following steps:

a) Choosing the product family: selecting a product family made up of a group of products that go through similar processing stages;

b) Drawing the current and future state: drawing the current and future state, based on information collected on the shop floor;

c) Work and implementation plan: prepare an implementation plan describing how the future state is to be reached.

3 Methodology

The methodological approach of this article, in terms of its nature, is classified as a case study, as it is used to collect and evaluate data aimed at supporting theoretical development in practical fields using the literature presented by [10].

The execution of the value stream map (VSM) begins by choosing a product family. From there, the production flow must be followed from the raw material supplier to the customer, with a detailed representation of the current state map, its material and information flows [10]. The current map is then analyzed and the seven losses must be taken into account.

In order to record the current process map, the customer and its demand were defined, the basic production processes and their main information were identified, the flows between the processes were drawn, the location of intermediate stocks and the quantities observed were established, and the suppliers and the flow of raw materials were identified.

The following points describe in more detail the step-by-step methodology for applying the VSM.

Step 0 - Define a team to carry out the production flow analysis. The team should be made up of members from different areas, a multidisciplinary team with experience, knowledge of the production process, knowledge of the VSM and Lean, and aptitude;

Step 1 - Define product families, with products that share the same production line, according to the frequency and volume of demand;

Step 2 - Draw a map of the current state of the production process;

Step 3 - Analyze the current state to support the construction of the future state map;

Step 4 - Build the future state map, with an action plan;

Figure 2 shows the representation of the current value stream map made by the Kaizen team and the molded coil manufacturing operators. The team is flexible, with new employees and some with decades of experience in the industry.

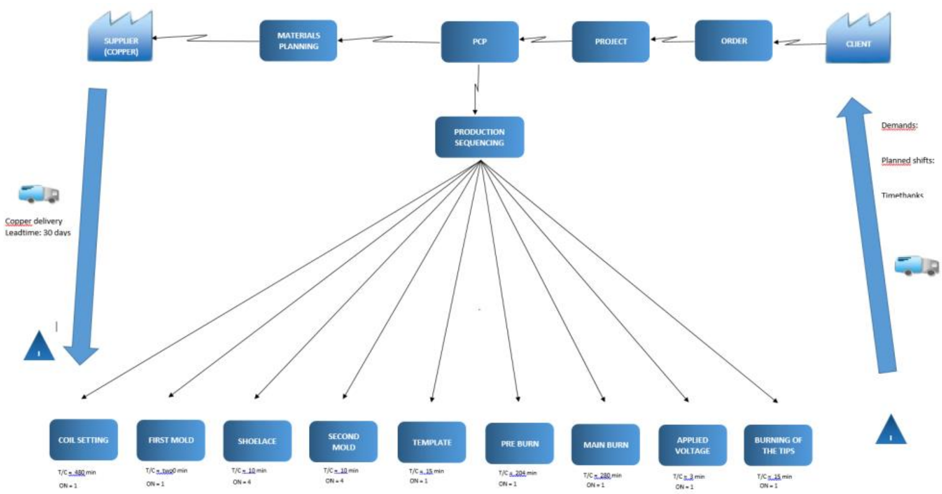

Fig. 2.: Current state VSM drawing
Source: Authors (2024)

The manufacturing process for molded coils can be classified into nine stages.

- Definition of the coil: Stage for separating the materials and analyzing the electrical design

- First mold: Stage for defining the size of the coil and setting up the machines

- Tying: Between the first mold and the second mold, the coil tying stage takes place.

- Second mold: Stage to define coil geometry and machine setup

- Template: The structured coil passes through the jig for final adjustments

- Pre-burn: The structured and insulated coil goes through a hot press to reduce the thickness of the insulation and consolidate the straight part.

- Main firing: Final hot press to prevent the insulation wall from having voids inside

- Applied voltage: All coils are tested to identify possible manufacturing faults or any short-circuits between turns

- Tip firing: Final cleaning and preparation for mounting the coils on the stator

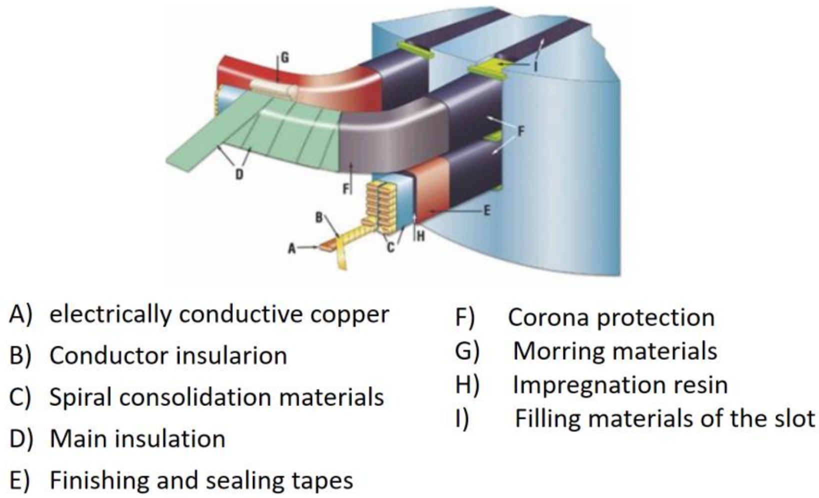

Fig. 3.: Cross-section in the straight part of the coil
Source: Martins (2010)

By looking at the current value stream map, it is possible to identify that the industry's lead time is high, due to the large volume of stocks in the process. Products are manufactured according to the production capacity of the coil burners and the capacity of the following processes is not taken into account, thus generating a large stock of products in production, leading to wasted stock, movement, overproduction and waiting.

The spaghetti diagram was also applied, which involves drawing the path taken by employees and/or materials in a unique layout, allowing waste to be seen through the movement of employees and the transportation of materials. This tool shows the mapping of irrelevant movement [12].

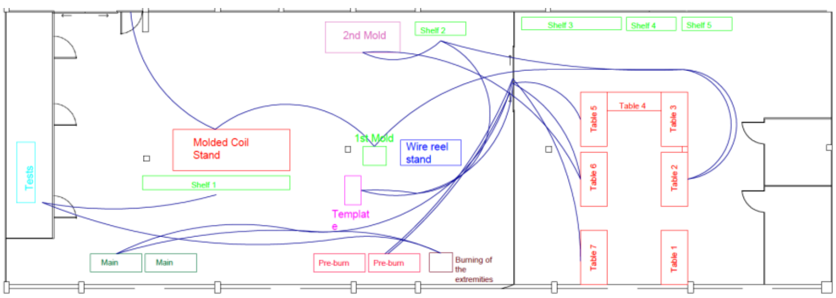

Fig. 4.: Spaghetti diagram for the coil process
Source: Authors (2024)

4 Results e Discussion

Analyzing the value flow of the process studied provided a macro view of the operations that add value to the product, as well as identifying the seven wastes in the production process, analyzing capacity, cycle times and takt time. To do this, it was necessary to collect data inherent to the processs studied, which resulted in a presentation of the flow characteristics, identification of losses and key points for possible improvements.

After analyzing the current flow map, the main points were identified and it was determined that the pre-firing and main firing process was the main bottleneck in leveling production. This led to the definition of an action plan for this process.

With the action plan in place, the layout analysis of the coil sector and the manufacture of mobile shelves, in order to achieve continuous production, the future state map was drawn up as shown in figure 5.

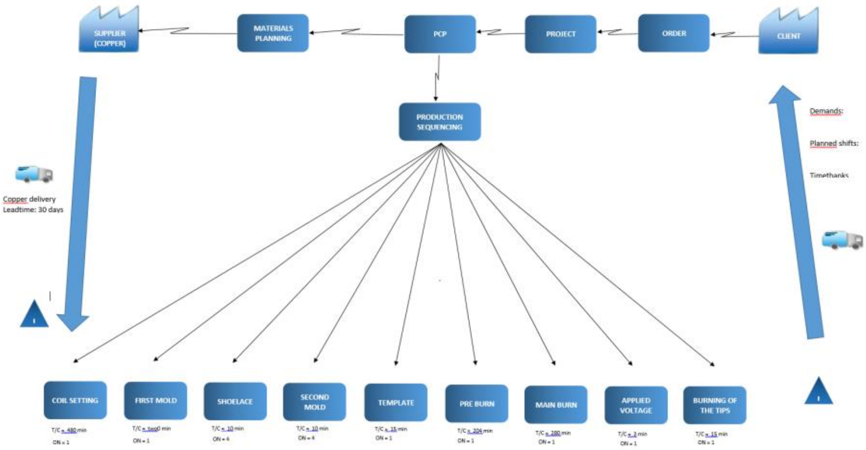

Fig. 5.: VSM drawing of the future state
Source: Authors (2024)

With the work of the Kaízen team, it was possible to arrive at the future value flow map. The map was assembled on the shop floor (gemba) with the help of the machine operators.

The results in practice represent a 20% reduction in lead time, a reduction in intermediate stocks and optimization of the layout, minimizing handling.

5 Conclusion

In view of the above, it is possible to conclude that the industry in question can achieve significant improvements if it implements the proposed improvements, gaining competitive advantages over its competitors.

The research was of great relevance to the company, enabling it to see the waste that until now had not been perceived, allowing the managers involved in the processes to look at them with a more critical eye.

An analysis of the current state was carried out in order to identify and propose improvements, in which some activities were identified that could be optimized and improved. Through the study, it was possible to put their treatment into practice, and by measuring the processes, the bottlenecks that slowed down and made the processes more costly were noticed.

In this way, it was possible to observe the manufacturing processes of molded coils from the industrial reality, and what the application of this tool could bring in terms of improvement. It was analyzed that if a company wants to remain competitive and maintain quality, it must be concerned about its processes, always examining whether there is any waste and whether the time spent on each activity is correct.

The two biggest difficulties in setting up this value stream mapping were the limitations encountered in the development of the study in relation to the lack of scientific studies that simultaneously relate Lean concepts and production to order or the restriction that industries have on not disclosing the data and results of studies and, as it is a very specific product, the issue of manufacturing coils is artisanal and manual and mainly requires the commitment of the work teams.

The study's strategy contributes to the academic scene by stimulating studies in the area of made-to-order production, linked to the principles of sustainable operations and the adoption of digital transformation.

It confirms the importance of using lean manufacturing methods in practice in serial and made-to-order production industries in order to remain more competitive in the market.

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