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Analysis and Mapping of Internal Logistics Flows of Materials and Semi-finished Products in the Value Stream Circond 1.0: A Lean Manufacturing Approach

Analisi e Mappatura dei Flussi Logistici Interni di Materiali e Semilavorati nella Value Stream Circond 1.0: un Approccio basato sui Principi della Lean Manufacturing

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qui devo scrivere la dedica della tesi

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Abstract

This thesis, titled "Analysis and Mapping of Internal Logistics Flows of Materials and Semi-finished Products in the Value Stream Circond 1.0: A Lean Manufacturing Approach", presents a comprehensive investigation into the implementation of Lean Manufacturing principles within the production processes of Circond 1.0, a facility dedicated to the manufacturing of stainless steel heat exchangers. The primary objective of this study is to analyze and optimize the internal logistics flows of materials and semi-finished products, thereby enhancing operational efficiency and reducing waste throughout the value stream.

The research employs various lean tools, including Spaghetti Chart and Value Stream Mapping (VSM), to identify sources of waste and analyze their root causes throughout the value chain. By systematically assessing the movement of materials, the study highlights critical areas for improvement, proposing actionable strategies to streamline processes and enhance value creation. The findings demonstrate that the integration of Lean principles not only fosters a culture of continuous improvement but also significantly contributes to reduced Lead Times, improved product quality, reduces production waste and increased customer satisfaction.

Implementing Lean Manufacturing practices is crucial in today's competitive landscape, as it empowers organizations to respond swiftly to market demands while minimizing costs. This thesis underscores the importance of Lean methodologies in transforming operational paradigms, advocating for their adoption as a strategic framework for driving innovation and sustainability in manufacturing environments. Ultimately, this work provides valuable insights for industry practitioners aiming to enhance their operational performance and achieve long-term success through Lean principles.

Sunto esteso in italiano

Questa tesi, dal titolo "Analisi e Mappatura dei Flussi Logistici Interni di Materiali e Semilavorati nella Value Stream Circond 1.0: un Approccio basato sui Principi della Lean Manufacturing" presenta un'indagine completa sul l'attuazione del Lean Principi di fabbricazione nel l'ambito dei processi produttivi di Circond 1.0, un impianto dedicato alla produzione di scambiatori di calore in acciaio inox.

La ricerca impiega vari strumenti di lean, tra cui Spaghetti Chart e Value Stream Mappatura (VSM), per identificare le fonti di spreco e analizzarne le cause alla radice attraverso la catena del valore. Valutando sistematicamente il movimento dei materiali, lo studio evidenzia le aree critiche per il miglioramento, proponendo strategie attuabili per razionalizzare i processi e migliorare la creazione di valore.

L'applicazione della Spaghetti Chart nel flusso di valore dello scambiatore di calore Riello 20 kW ha fornito informazioni significative sulle inefficienze operative presenti nel processo produttivo di VALMEX S.p.A. Grazie a questa analisi sono state identificate sfide critiche, e in risposta a queste sfide è stata sviluppata una serie di proposte mirate al miglioramento, concentrandosi sulla razionalizzazione del flusso materiale e sul miglioramento dell'organizzazione del luogo di lavoro.
Inoltre, l'applicazione della Value Stream Mapping (VSM) ai processi produttivi il bruciatore e lo scambiatore di calore Riello da 20 kW hanno rivelato notevoli inefficienze, da cui sono nate opportunità di miglioramento.
Applicando i miglioramenti individuati, VALMEX S.p.A. può migliorare significativamente la propria efficienza operativa, ridurre gli sprechi e rafforzare la propria posizione competitiva sul mercato. In definitiva, questa tesi dimostra che l'applicazione strategica dei principi Lean attraverso strumenti come VSM e Kanban può portare a progressi sostanziali nell'ottimizzazione dei processi e nella produttività complessiva.

I risultati dimostrano che il l'integrazione dei principi Lean non solo favorisce una cultura del miglioramento continuo, ma contribuisce anche in modo significativo a ridurre i tempi di consegna, migliorare la qualità del prodotto, riduce gli sprechi di produzione e aumenta la soddisfazione dei clienti.

Chapter 1

Introduction

In recent decades, manufacturing industries worldwide have sought methodologies to enhance operational efficiency, reduce waste, and improve overall quality. Among these, Lean Manufacturing has emerged as one of the most effective paradigms for optimizing production processes, earning widespread application across both manufacturing and service industries. Initially developed within Japan's automotive sector, particularly by Toyota, Lean Manufacturing centers on the systematic elimination of waste to add value from the customer's perspective. Through its focus on maximizing quality and minimizing costs, Lean Manufacturing supports companies in maintaining competitive advantage, fostering innovation, and meeting customer demands more effectively. The goal of Lean Manufacturing is clear: eliminate non-value-added activities to streamline processes, reduce costs, and improve both product quality and lead times.

This thesis explores the application of Lean Manufacturing principles within Circond 1.0, the value stream dedicated to stainless steel heat exchanger production at VALMEX S.p.A., a company specializing in high-performance heat exchangers. Operating in a highly competitive market, VALMEX must prioritize efficient, high-quality production to maintain a competitive edge. This research focuses specifically on the internal logistics flows within Circond 1.0, where inefficiencies in the handling of materials and semi-finished products have been identified. Through a systematic application of Lean principles, the study aims to identify key sources of waste, analyze their root causes, and propose targeted improvements to streamline production and enhance overall operational efficiency.
Lean Manufacturing is founded on a set of core principles, including defining customer-perceived value, establishing a continuous flow, and striving for perfection through waste elimination. Tools such as Value Stream Mapping (VSM) and Spaghetti Chart enable detailed analysis of both material and information flows, allowing organizations to uncover inefficiencies and enhance resource utilization. The Lean philosophy, though rooted in historical challenges faced by post-war Japan, has evolved significantly with advancements in digital technologies, offering new avenues for achieving precision, flexibility, and efficiency in modern manufacturing.
The primary objective of this research is to systematically analyze and map the value stream of Circond 1.0 to identify and reduce waste points. Utilizing the Lean tools

of Value Stream Mapping (VSM) and Spaghetti Chart analysis, this study aims to propose improvements that enhance the efficiency and effectiveness of internal logistics flows.

The structure of this thesis is organized to guide the reader through a comprehensive examination of Lean principles, their practical application, and the results of these initiatives within VALMEX S.p.A.

Chapter 2, *Production Optimization: From Lean Principles to Digital Transformation*, offers a comprehensive analysis of Lean Manufacturing, covering its foundational principles and tools, such as the Spaghetti Chart and Value Stream Mapping, for identifying waste and optimizing workflows. The chapter examines the evolution of Lean strategies within the context of modern industrial challenges and opportunities. It explores the Toyota Production System (TPS) and its key concepts, like the 7 wastes and the roles of Muda, Mura, and Muri in targeting inefficiencies, along with tools such as Kaizen, PDCA, 5S, TPM, and Six Sigma, all aimed at improving efficiency, quality, and reducing costs. The chapter also discusses push and pull flow systems and emphasizes the customer-driven pull system in Lean planning. Finally, it addresses the integration of Lean with Industry 4.0 technologies, illustrating the potential for enhanced precision in monitoring and waste reduction in today's digitalized industrial landscape.

Chapter 3, *VALMEX S.p.A. and the Production of Heat Exchangers*, provides an operational context for applying Lean principles within VALMEX S.p.A.'s manufacturing processes. It begins with a historical overview of the company, examining its growth and specialization in heat exchangers production. The chapter then focuses on the manufacturing steps of VALMEX's core products, emphasizing the Circond Monotermic product line, a high-performance stainless steel heat exchanger representing the company's commitment to reliability and quality, the production of which will be a central element in thesis. Follows a thorough analysis of Circond Monotermic's technical characteristics, covering its range, dimensions, functional principles, and advantages of its single-coil design. Additionally, this section highlights the rigorous validation and certification processes that ensure the product's reliability and market success. Finally, the chapter details the key production stages for the production Circond Monotermic, specifically examining the processes at Tube Line 2, Automatic Island 5, and Assembly Station 4, each of which plays a central role manufacturing chain of Circond Monotermic.

Chapter 4, *Application of Lean Tools to the Production of Value Stream 1.0*, is an essential section that demonstrates the practical application of Lean tools in the production of the Riello 20 kW heat exchanger, one of the most produced models in the company. This chapter examines the use of Spaghetti Charts and Value Stream Mapping (VSM) to enhance workflow efficiency within Value Stream 1.0 by identifying and reducing waste in internal logistics. It begins with the application of Spaghetti Charts, tracking the movement of operators and materials to uncover inefficiencies and excessive transportation on the production line. The focus then shifts to Value Stream Mapping, showcasing its role in mapping key production processes and identifying non-value-added activities that can be minimized. This chapter is essential in bridging lean theory with real-world application, demonstrating how Lean methodologies can optimize production efficiency and establish a structured approach to waste reduction at VALMEX.

Chapter 5, *Analysis of Results and Lean Improvement Proposals*, is the most important chapter of the thesis, as it presents a critical evaluation of the outcomes from applying Lean tools to the production of the Riello 20 kW heat exchanger and offers targeted improvement proposals. The chapter provides an in-depth analysis of inefficiencies identified through Spaghetti Charts and Value Stream Mapping (VSM), highlighting specific areas for optimization. It proposes enhancements to the Work In Progress (WIP) area using the 5S methodology and suggests implementing the Mizusumashi Train System and a Milk Run Cycle to improve material flow. Additionally, the chapter discusses improvement proposals derived from VSM, focusing on both Riello 20 kW and Burner production processes. By addressing the challenges revealed during Lean tool application, this chapter provides actionable solutions aimed at solving critical issues, aligning with VALMEX's production goals, and fostering a culture of continuous improvement within the organization.

Finally, Chapter 6, *Conclusion*, presents the conclusions drawn from this research, reflecting on the significant improvements achieved through the application of Lean Manufacturing principles at VALMEX. This chapter summarizes the key findings regarding the implementation of Lean tools, particularly Spaghetti Charts and Value Stream Mapping (VSM), which identified critical inefficiencies within the production processes of heat exchanger and consolidates the research findings, reflecting on the impact of Lean principles in optimizing logistics and production at VALMEX.

In summary, this thesis contributes to the understanding and application of Lean Manufacturing principles in a specialized production setting, with the aim of reducing waste, improving product quality, and ultimately strengthening VALMEX's market position. By employing a structured Lean approach, this study highlights the tangible benefits of continuous improvement and offers actionable insights for future advancements in process optimization.

Chapter 2

Production Optimisation: From Lean Principles to Digital Transformation

2.1 Introduction to Lean Manufacturing and Lean tools

Lean manufacturing, or also known as Lean Production, has been one of the most popular paradigms in waste elimination in the manufacturing and service industry [1].
Originating from the Japanese manufacturing industry, particularly Toyota, this methodology focuses on minimizing waste to enhance the value of products. The core objective of Lean Manufacturing is to systematically reduce waste in all its forms, thereby improving the efficiency of processes and increasing the value delivered to customers. This philosophy of production is founded on two main pillars: achieving high product quality at a low cost and ensuring customer satisfaction.

Lean Manufacturing is fundamentally a philosophy centered on continuous improvement, closely associated with principles such as Kaizen, a concept which we will discuss in more detail below. It focuses on maximizing resource utilization by minimizing waste and was particularly relevant in the post-World War II era, when Japan faced severe shortages of resources, capital, and skilled labor. During this period, Lean principles were introduced into Japanese automotive manufacturing as a way to achieve greater efficiency with limited resources [2].

Lean Manufacturing has its origins in the Japanese company Toyota and is an evolution of the Toyota Production System (TPS), a production philosophy of which we will talk shortly. The system was pioneered by Sakichi Toyoda, along with his sons Kiichiro and Eiji Toyoda, and further developed by Taiichi Ohno.
In 1929, Kiichiro Toyoda visited the United States, where he was deeply impressed by Ford's mass production system. Inspired by this, Kiichiro decided to adapt and implement the lessons learned at Toyota. Taiichi Ohno, a manufacturing engineer, further refined the TPS during the 1940s and, later, integrated advancements in computing during the 1980s, which facilitated the system's evolution [3].

In the current highly competitive environment, companies across various industries strive to deliver high-quality products in large volumes while keeping costs as low as

possible, and Lean Manufacturing serves as a vital tool in achieving these objectives [2]. Due to rapidly changing business environment the organizations are forced to face challenges and complexities. Any organization whether manufacturing or service oriented to survive may ultimately depend on its ability to systematically and continuously respond to these changes for enhancing the product value [4].
Lean manufacturing was developed with the goal of maximizing resource utilization by minimizing waste, and it was further refined as a response to the dynamic and competitive nature of the business landscape.

At its core, Lean Manufacturing focuses on maximizing customer value while minimizing waste. The ultimate goal of implementing Lean principles is to improve productivity, enhance product quality, reduce Lead Times, and lower costs. These key factors serve as performance indicators of a successful lean production system, reflecting the efficiency and effectiveness of its application within an organization [1]. Lean Thinking is applied to optimize every aspect of production, and the image (2.1) illustrates the core ideas of Lean Thinking, starting with the identification of value from the customer's perspective and then moving through analyzing the value stream to eliminate waste, ensuring a continuous flow of activities.

Figure 2.1: Components of Lean Thinking

The primary objective of Lean Manufacturing is therefore to minimize product costs across all stages of production, including design, fabrication, and manufacturing, by utilizing insights gathered from previous business analyses. This systematic approach ensures that resources are used efficiently, resulting in cost reductions and process optimization. Its purpose is so to eliminate inefficiencies within the project, thereby reducing waste in terms of both time and cost.
To achieve this, industries must first identify and categorize all forms of hidden waste. Waste can arise from various causes, and its elimination requires thorough analysis and understanding. This can be accomplished by expanding and evaluating a comprehensive checklist aimed at reviewing the design and manufacturing processes of goods, as suggested by various frameworks. Once these waste sources are identified, they can be minimized or eliminated through targeted corrective actions [2].

The Lean Manufacturing philosophy has nowadays become a key tool for achieving high quality and safety, while simultaneously reducing costs, shortening lead times, and boosting employee morale. Though initially developed for the automotive industry, Lean Manufacturing principles have proven applicable across a wide range of industries worldwide. The methodology rapidly spread as manufacturers recognized its effectiveness in eliminating waste and driving operational excellence .

2.1.1 Lean Manufacturing principles

Lean principles defines the value of the product/service as perceived by the customer and then making the flow in-line with the customer pull and striving for perfection through continuous improvement to eliminate waste by sorting out Value Added activity(VA) and Non-Value Added activity (NVA). The sources for the NVA activity wastes are Transportation, Inventory, Motion Waiting, Overproduction, Over processing and Defects. The NVA activity waste is vital hurdle for VA activity. Elimination of these wastes is achieved through the successful implementation of lean elements [4]. As discussed, lean manufacturing has its principles that ensure its proper implementation. According to the book, "lean manufacturing" by James Womack and Dan Jones, the five basic principles of lean manufacturing are [2]:

- **Value:** customer satisfaction is the ultimate goal. This is because every customer assigns a value to its product.
- **Value stream mapping:** mapping can be understood as connecting various links to establish a perfect working environment.
- **Flow:** flow ensures that there is no interruption in the journey of the product from planning, production to customer.
- **Pull:** pull system states that nothing will start until and unless there is a signal from the customer's side. The only customer can 'pull' the product they need.
- **Finding perfection:** at last, what is important is perfection. This is something that separates a producer from the rest.

The following image (2.2) represents a structured cycle that perfectly reflects the principles of Lean Management. From recognizing waste to eliminating it, and monitoring and measuring progress, each step is geared towards creating a more efficient and continuously improving work environment. This cycle not only helps to reduce costs and improve quality, but also creates a more responsible and operational efficiency-oriented corporate culture.

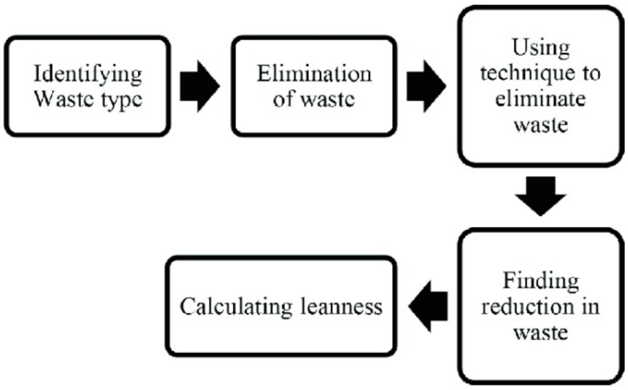


Figure 2.2: Process of lean implementation

2.1.2 Lean analysis tools: Spaghetti Chart and Value Stream Mapping

In the context of production processes, the **Spaghetti Chart** and the **Value Stream Map (VSM)** are essential tools in Lean Manufacturing used to analyze operational efficiency.
Their primary purpose is to identify inefficiencies and waste, providing a solid foundation for implementing improvements and optimizing activities within the production flow.

Spaghetti Chart

The Spaghetti Chart is a graphical representation of the movements of operators or materials within a process. Visually trace the path taken within the production area, and it gets its name from the resulting appearance of the chart, which often resembles a tangle of spaghetti due to the complex and overlapping pathways that are tracked during the analysis.

The Spaghetti Chart is a powerful monitoring and analysis tool that helps practitioners gain a comprehensive overview of the work in progress on the shop floor. Its application highlights the movement of workers as they carry out assigned tasks, visually mapping the flow of activity.
This tool is particularly effective in revealing inefficient layouts and identifying excessive distances traveled between key steps in the production process. By visualizing unnecessary movements of workers, products, or materials, Spaghetti diagrams expose areas where time and resources are wasted [5].

The Spaghetti chart is a tool that helps to:

- Identify waste, revealing excessive walking, transporting, or handling that may occur within the production process, which can lead to delays or higher operational costs.

- Improve layout, since once inefficiencies are identified, the layout of the workspace or production line can be redesigned to minimize unnecessary movement, leading to greater efficiency and faster production times.
- Enhance workflow, considering that the chart provides a clear view of the physical flow of processes, enabling the optimization of workflows and improving overall productivity.

The Integration of real-time data acquisition into this process can significantly enhance the reliability and speed of developing Spaghetti Charts, overcoming the limitations of traditional methods, which are often time-consuming and prone to long-term errors [5]. These traditional approaches may negatively impact production performance, safety, and ergonomics, particularly concerning human factors.

In the figure below is remarked a generic example of how a spaghetti chert looks like.

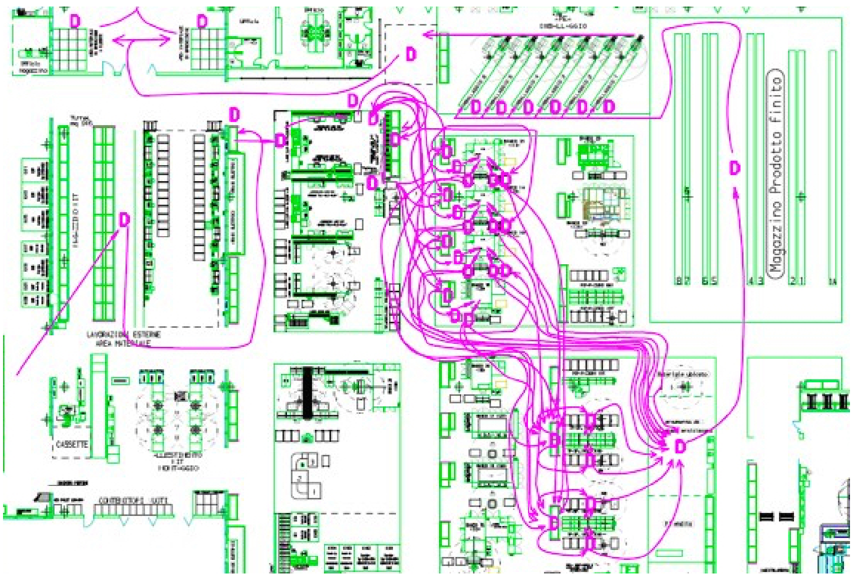


Figure 2.3: Generic example of Spaghetti Chart

Value Stream Map

The Value Stream Map (VSM) is one of the most important tools in Lean Manufacturing to analyze and optimize the entire production process, from raw material to finished product. Unlike the Spaghetti Chart, which focuses on physical movement, the VSM provides a complete and detailed representation of the flow of materials and information in a process.

Value Stream Mapping is a powerful tool for enterprise improvement, aimed at visualizing the entire production process by representing both material and information flow. The value stream encompasses all activities—both value-added and non-value-added—required to guide a product, or a group of products using the same

resources, through the primary flows, from raw materials to the end customers.
In an effort to collect data in a uniform manner, a VSM was used as the tool for summarizing the flow of product through each department. This tool served two purposes. First, the VSM provided a focused reason for the observation. Second, it provided a system wide view of both information and product flow. Data collected during the Value Stream Mapping process included manufacturing processes in each area, the technical tools needed, the placement of machines and support equipment, and the flow of data and paper through the department [6].

Unlike other process mapping techniques that typically document only the basic product flow, VSM also captures the flow of information within the system. This includes key data on where materials are stored, such as raw materials and work in process (WIP), and what triggers the movement of these materials between different stages of production. This dual documentation of both material and information flows provides a more comprehensive view of the entire production system, enabling more targeted and effective improvements [7].

VSM is a valuable tool for analyzing value flows, and its most notable strengths are [8]:

- Fast and easy to carry out;
- Cost-effective, as no special tools or computer programs are needed. Only man-hours are required during the initial phase;
- Simple to learn and understand;
- Requires only pen and paper;
- Provides a solid basis for discussions and decision-making;
- Enhances understanding of customer needs, the product, the information flow, and sources of waste;
- Can often be conducted with the participation of individuals directly involved in the system, with the guidance of an experienced VSM practitioner.

There are also some limitations with VSM, as it is typically used [8]:

- Only the flow of a single product or product type is analyzed per VSM analysis;
- The VSM provides a snapshot of the situation on the shop floor at a specific moment in time;
- The VSM map is a rough simplification of the actual situation;
- It is difficult to experiment with proposed new systems and layouts.

In the following picture is graphically represented a generic example of Value Stream Map.

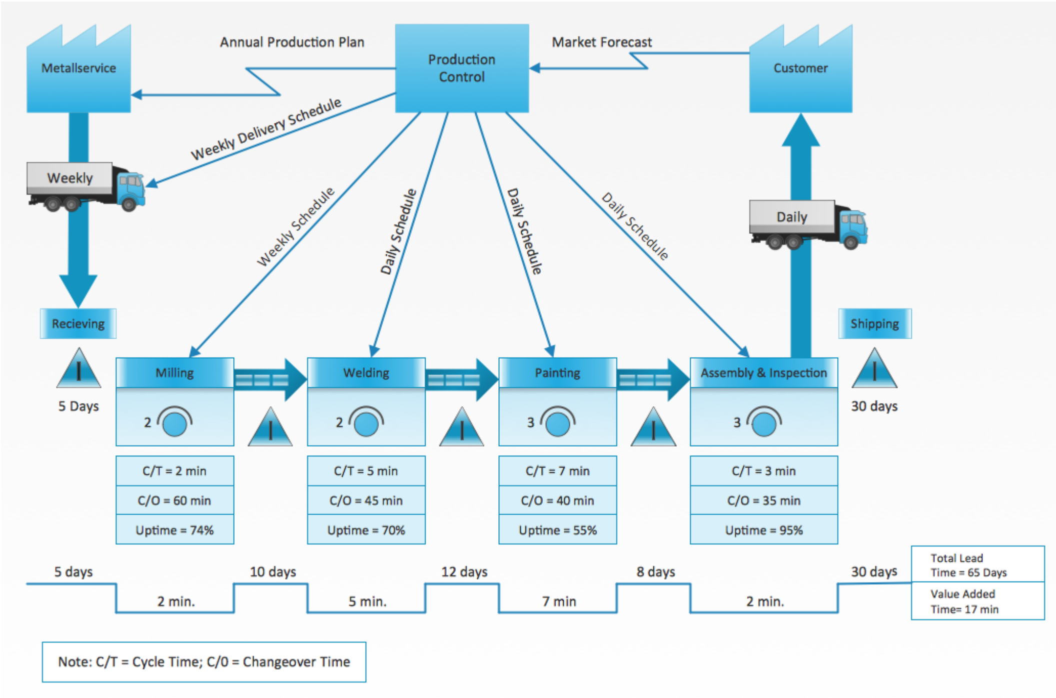


Figure 2.4: Generic example of Value Stream Map

2.1.3 Trends, Challenges and Opportunities

Lean has proven itself to be positively effective in most of the fields by reducing any kind of waste, either it is a product, time, or an action. Hence, the increase in financial performance and the sustainability of the work appear to have been inevitable. By value stream mapping technique [2.1.3], it is easier to see waste movement a product, or a worker, and fix it. While using techniques like Kanban, JIT, six sigma etc. value stream mapping helps a lot to see what is actually going on with the production, even to the smallest details. The technique is quite promising [3].
The image (2.5) summarizes how various industries are adopting a methodology that reduces waste and improves efficiency, though challenges like management resistance and quality control persist. Nonetheless, it offers broad applicability and future research potential.

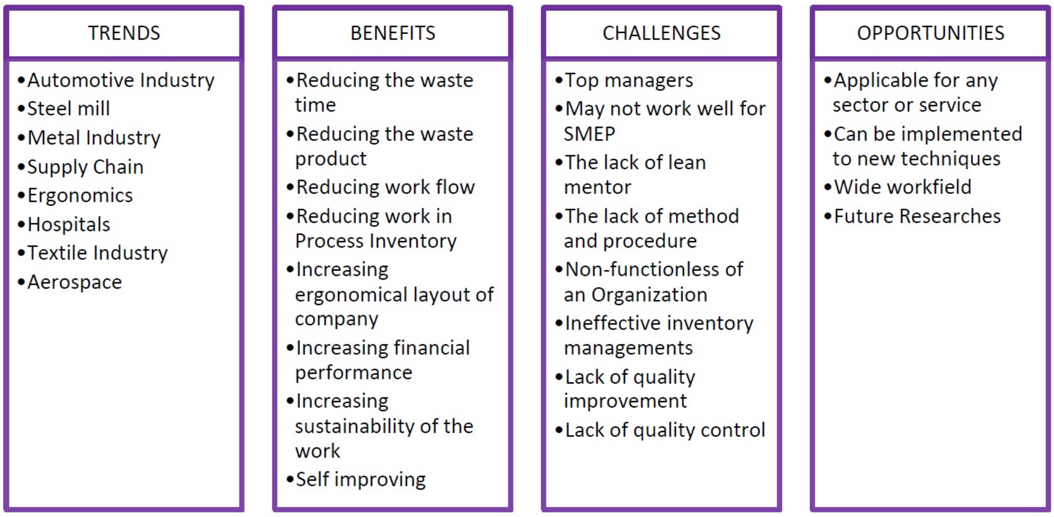


Figure 2.5: Summary of trends, benefits, challenges and opportunities

However, implementing Lean is not without its challenges. Top management plays a critical role in decision-making, and many executives may be reluctant to invest the necessary effort to adopt Lean practices due to the varying outcomes observed across different companies. Uncertainty about its effectiveness within their own organization often leads to hesitation. To successfully implement Lean, it is essential for managers to seek guidance from a mentor or Lean consultant. With expert support, top managers can work systematically, starting from the beginning of the production process, to identify and eliminate obstacles, paving the way for a smoother implementation [3].

2.2 Toyota Production System

The **Toyota Production System (TPS)** was developed and promoted by Toyota Motor Corporation and is being adopted by many Japanese companies in the aftermath of the 1973 oil shock. The main purpose of the system is to eliminate through improvement activities various kinds of waste lying concealed within a company.

The foundational concept of TPS, as repeatedly emphasized, is the thorough elimination of waste. As Toyota approached this goal, it became increasingly clear that businesses must address the individual needs of each customer, highlighting the importance of human individuality over mass production.
Unlike the Ford production system, which focuses on large-scale, homogeneous manufacturing, the Toyota Production System is more adaptable and efficient, aiming to produce customized items on a one-at-a-time basis. This approach minimizes waste and reduces costs by tailoring production to specific customer demands, avoiding the inefficiencies associated with mass production.
In this sense, TPS demonstrates that a more personalized and flexible production model leads to greater overall efficiency and cost reduction, setting it apart as a revolutionary system in modern manufacturing [9].

2.2.1 The purposes of Toyota Production System

The goals of the TPS are to focus on production efficiency and reducing waste through continuous improvement. The main purposes of TPS are are discussed in the following paragraphs.

Profit through Cost Reduction

The primary goal of the Toyota Production System is cost reduction, or improvement of productivity. Cost reduction and productivity improvement are attained through the elimination of various wastes such as excessive inventory and excessive workforce [10].

Elimination of Overproduction

The principal consideration of the Toyota Production System is to reduce costs by completely eliminating waste. Four kinds of waste can be found in manufacturing production operations:

1. Excessive production resources
2. Overproduction
3. Excessive inventory
4. Unnecessary capital investment

All four sources of waste contribute to increased administrative expenses, direct material costs, labor costs (both direct and indirect), and overhead expenses such as depreciation. Since an excessive workforce is often the initial source of waste in the production cycle, and it tends to lead to additional forms of waste, it is crucial to prioritize the reduction or elimination of this inefficiency first [10].

Quantity Control, Quality Assurance, Respect for Humanity

Although cost-reduction is the system's most important goal, it must first meet three other subgoals:

1. Quantity control, which enables the system to adapt to daily and monthly fluctuations in demand of quantity and variety.
2. Quality assurance, which assures that each process will supply only good units to subsequent processes.
3. Respect for humanity, or morale, which must be cultivated while the system utilizes human resources to attain its cost objectives.

It should be emphasized here that these three goals cannot exist independently or be achieved independently without influencing each other or the primary goal of cost reduction. It is a special feature of the TPS that the primary goal cannot be achieved without realization of the subgoals and vice versa. All goals are outputs of the same system; with productivity as the ultimate purpose and guiding concept, the TPS strives to realize each of the goals for which it has been designed [9].

Just-in-Time and Autonomation

A continuous flow of production across the entire organization or supply chain, as well as the ability to adapt to fluctuations in demand, both in terms of quantity and product variety, is achieved through the implementation of two key principles: Just-in-Time (JIT) and Autonomation.
These two concepts form the foundational pillars of the TPS [10].

- **Just-in-Time (JIT)** refers to the practice of producing only the required units, in the exact quantities needed, and at the precise time they are required. This approach aims to minimize inventory and streamline production efficiency.
- **Autonomation**, or "Ninben-no-aru Jidoka" in Japanese (often abbreviated to **"Jidoka"**), refers to an automated process with a human element, specifically focused on defect control. It ensures that defective units from one stage of production are not allowed to pass into subsequent stages, thereby preventing disruptions in the overall production flow. Jidoka plays a critical role in supporting JIT by ensuring that quality is maintained at every step of the process, further contributing to the seamless operation of the Toyota Production System.

Therefore, as you can see in the image (2.6), at the heart of TPS are this two core principles, which work in synergy to drive efficiency, quality, and adaptability in Toyota's manufacturing process. Together, these pillars create a system that minimizes waste, maximizes quality, and enables continuous improvement.

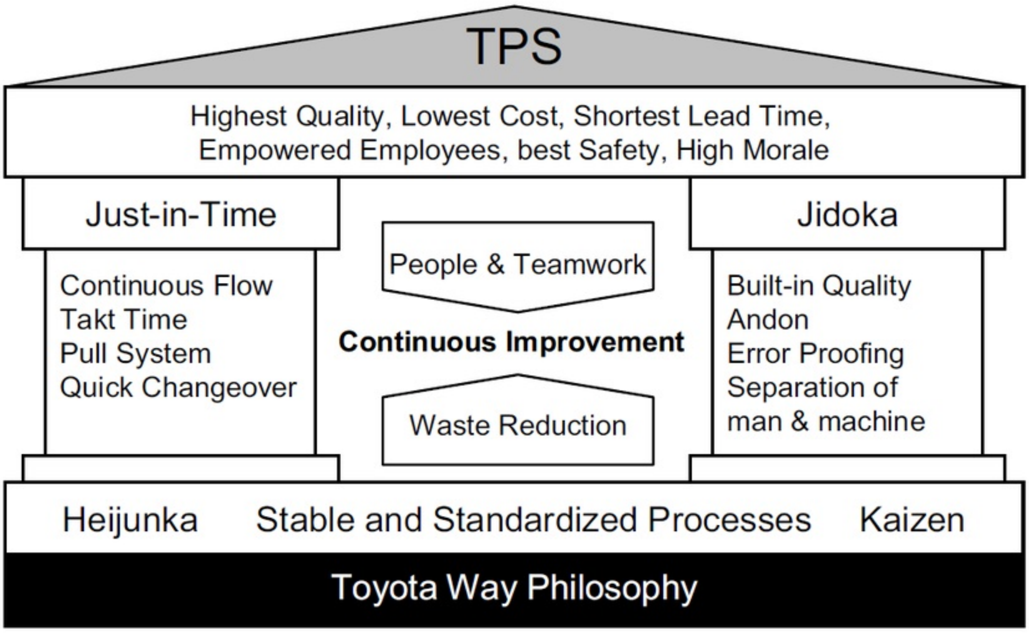


Figure 2.6: The principles of Toyota Production System

Flexible workforce and originality and ingenuity

Two key concepts in the Toyota Production System are the flexible workforce, referred to in Japanese as "Stotinka," which involves adjusting the number of workers in response to changes in demand, and creative thinking or inventive ideas, known as "Seiko," which emphasizes the importance of leveraging employee suggestions [10].

2.3 The 7 wastes

The elimination of waste is the primary goal of any lean system. In effect, lean declares war on waste – any waste. Waste is anything that does not have value or does not add value and, in addition, is something the customer will not pay for [11].

The seven wastes originated in Japan, where waste is known as **"Muda"**. The seven wastes is a tool to further categorize muda and, as we have said in paragraph [2.2], was originally developed by Toyota's Chief Engineer Taiichi Ohno as the core of the Toyota Production System, also known as Lean Manufacturing. To eliminate waste, it is important to understand exactly what waste is and where it exists [12].

Wastes can be categorized into two types: obvious wastes and hidden wastes. It is crucial to identify and eliminate the latter, as they often represent a larger proportion of inefficiencies.
The concept of waste can be visualized as an iceberg; the visible tip signifies the obvious wastes, while the substantial bulk submerged underwater symbolizes the hidden wastes.
Wastes can manifest in various forms, including unnecessary output, input, or processing. They may relate to materials, inventory, equipment, facilities, labor hours, utilities, documentation, expenses, movement, and other activities that do not contribute value [11].
The steps to effective waste elimination are:

1. Make waste visible;
2. Be conscious of the waste;
3. Be accountable for the waste;
4. Measure the waste;
5. Eliminate or reduce the waste.

In other words, before one can stop waste, he should able to see it, recognize it as waste, identify who is responsible, and finally appreciate its size and magnitude [11].

2.3.1 Muda, Mura, Muri

In Lean Manufacturing, the principles of Mura, Muri, and Muda are fundamental to enhancing production efficiency and reducing waste.

Mura

Muri refers to unevenness in production volume. The wild fluctuations due to extreme highs (peaks) and lows (valleys) in production scheduling cause periods of overload and long idle time [11].

Muri

Muri refers more specifically to overloading an equipment, facility, or human resource beyond its capacity. This undue stress may cause downtime, defects, delays, and even disasters [11].

Muda

The most critical concept is Muda, which encompasses all forms of waste—activities that do not add value to a product or service. By effectively identifying and eliminating Muda, organizations can enhance efficiency, reduce costs, and foster a culture of continuous improvement.

These wastes are classified into 7 types:

1. **Overproduction waste:** Simply put, overproduction is to manufacture an item before it is actually required. Overproduction is highly costly to a manufacturing plant because it prohibits the smooth flow of materials and actually degrades quality and productivity [12].

2. **Waiting waste:** Whenever goods are not moving or being processed, the waste of waiting occurs. Typically more than 99% of a product's life in traditional batch-and-queue manufacture will be spent waiting to be processed. Much of a product's lead time is tied up in waiting for the next operation [12].

3. **Transport waste:** Transporting product between processes is a cost incursion which adds no value to the product. Excessive movement and handling cause damage and are an opportunity for quality to deteriorate [12].

4. **Over processing:** Often termed as "using a sledgehammer to crack a nut", many organizations use expensive high precision equipment where simpler tools would be sufficient. This often results in poor plant layout because preceding or subsequent operations are located far apart [12].

5. **Inventory waste:** Work in Progress (WIP) is a direct result of overproduction and waiting. Excess inventory tends to hide problems on the plant floor, which must be identified and resolved in order to improve operating performance. Excess inventory increases Lead Times, consumes productive floor space, delays the identification of problems, and inhibits communication [12].

6. **Motion waste:** This waste is related to ergonomics and is seen in all instances of bending, stretching, walking, lifting, and reaching [12].

7. **Defects:** Having a direct impact to the bottom line, quality defects resulting in rework or scrap are a tremendous cost to organizations. Associated costs include quarantining inventory, re-inspecting, rescheduling, and capacity loss.

In many organizations the total cost of defects is often a significant percentage of total manufacturing cost [12].

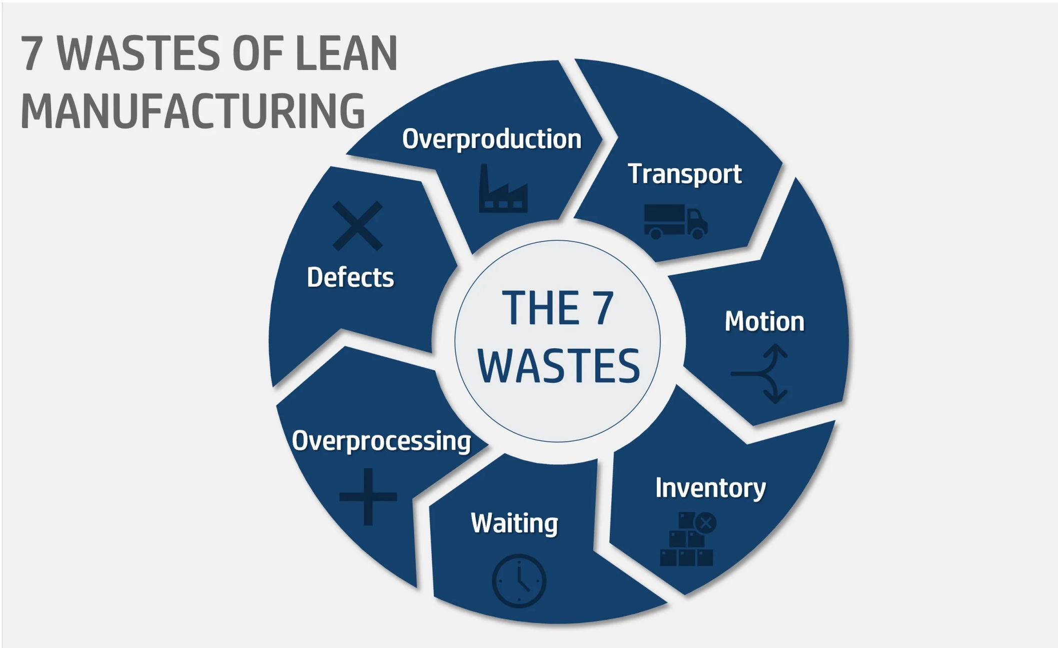


Figure 2.7: The 7 wastes

2.4 Continuous Improvement Tools: Kaizen and PDCA, 5S, TPM, SMED and Six Sigma

In the context of lean manufacturing, the implementation of continuous improvement tools is essential to optimize production processes and reduce waste.
Among these tools, Kaizen and PDCA cycle, the 5S methods, TPM, SMED and Six Sigma have proved particularly effective. Each of these approaches offers a set of practices and methodologies that, when applied synergistically, can lead to significant improvements in quality, efficiency and customer satisfaction.
This section will explore each of these tools, highlighting their main features and how they interact in promoting a culture of continuous improvement within organizations.

2.4.1 Kaizen and PCDA

The term Kaizen originates from the Japanese language, where it is a compound of two words: **Kai** meaning "change," and **Zen** meaning "for the better." This concept, which translates to "continuous improvement," has been widely adopted by companies around the world, particularly in the context of production and operations management. Kaizen embodies the philosophy that ongoing, incremental changes can lead to significant improvements in efficiency, productivity, and competitiveness over time [13]. In today's highly competitive global market, the importance of continuous improvement is more critical than ever, as it is recognized as one of the core strategies for achieving operational excellence.

Kaizen originated in Japan in the 1950s, emerging as a response to increasing global competition and the need to improve production efficiency. At a time when global competition and cost pressures were mounting, Toyota implemented Kaizen to enhance productivity and competitiveness. The approach quickly spread across Japan, becoming a fundamental component of the country's manufacturing success [13].

The philosophy of Kaizen promotes continuous improvement through incremental changes, which over time, lead to significant organizational benefits. This approach contrasts with radical or disruptive transformations, advocating instead for a systematic and consistent method of addressing operational challenges. A key concept in Kaizen is the Gemba ("the real place" or "the place of work"), emphasizing that improvements must be identified and implemented where operations are performed, making employee involvement crucial to the success of the process.

Kaizen is not limited to a single tool or technique but serves as an umbrella for various methods aimed at improving efficiency and productivity, as it can be noticed in 2.8. These include Kanban, Total Productive Maintenance (TPM), Six Sigma, Automation [2.2.1], the Just-In-Time (JIT) system [2.2.1], and many other initiatives designed to boost performance and streamline operations [13].

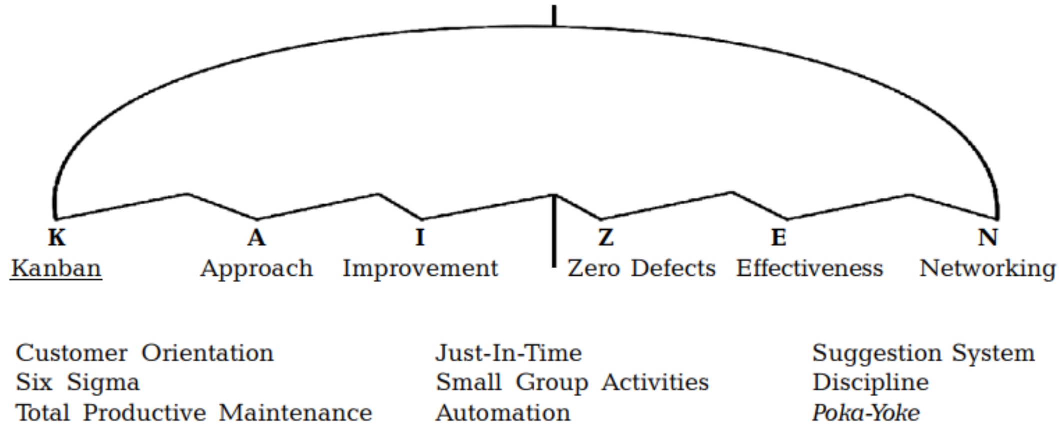


Figure 2.8: Representation of Kaizen umbrella

The Plan-Do-Check-Act cycle

In the context of continuous improvement, the Kaizen methodology and the Plan-Do-Check-Act (PDCA) cycle are fundamentally interconnected. During a Kaizen event, a team of experts convenes to address critical issues, brainstorm solutions, and develop actionable plans. This collaborative effort underscores the essence of Kaizen: fostering a culture of continuous improvement through collective problem-solving and innovation [14].

The PDCA cycle serves as a guiding framework for this process. In PDCA, the four phases Plan, Do, Check, and Act provide a structured approach to implement improvements:

1. **Plan:** the team identifies specific problems and formulates strategies to address them. This phase is crucial for establishing clear objectives and actionable steps.

2. **Do:** this phase involves executing the identified actions. This is where the ideas generated during the Kaizen event are put into practice, allowing the team to test the proposed solutions in a real-world setting.

3. **Check:** evaluating the effectiveness of the previous actions. This involves gathering data and feedback to determine whether the changes achieved the desired outcomes.

4. **Act:** entails analyzing the results from the Check phase and determining the next steps. If the actions were successful, they can be standardized and incorporated into the organization's practices. Conversely, if the results were unsatisfactory, the team can use the insights gained to refine their approach and initiate another cycle of improvement.

This cyclical nature of PDCA, as it's possible observe in image (2.9), complements the Kaizen philosophy, as it allows for continuous learning and adaptation. Each iteration of the PDCA cycle enhances the team's understanding of the issues at hand, enabling them to evaluate the effectiveness of their actions systematically.

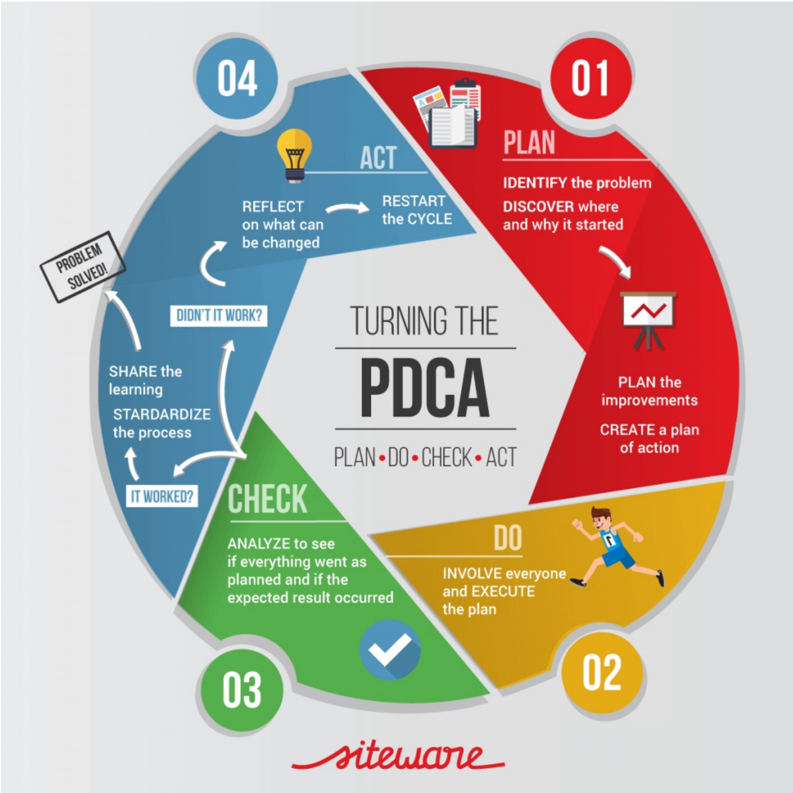


Figure 2.9: Cycle of PDCA

The image that follow (2.10) presents the PDCA cycle, outlining steps for continuous improvement. It involves identifying improvement areas, analyzing data, implementing solutions, and evaluating results. If goals are achieved, solutions are standardized; if not, corrective actions are taken, and the process repeats. Data collection and efficiency evaluation are integral throughout.

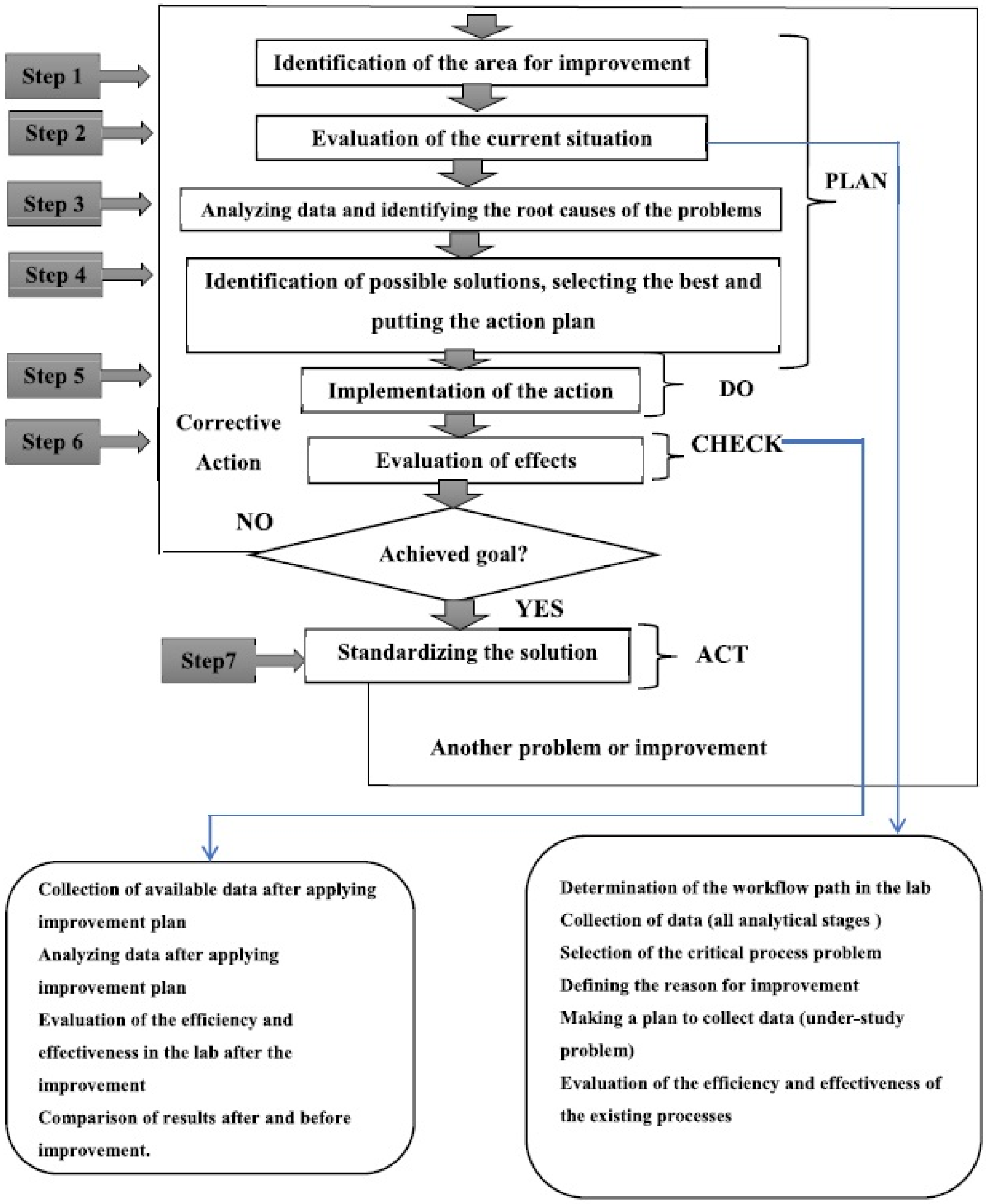


Figure 2.10: Steps in the methodology for the study based on PDCA cycle

Furthermore, the introduction of Kaizen Programming (KP) represents a novel evolutionary tool that combines the concepts of Kaizen with PDCA. KP serves as a computational implementation of a Kaizen event, facilitating the systematic application of the PDCA framework. This innovative approach enhances the ability to document, analyze, and refine the continuous improvement process, ensuring that organizations can effectively leverage the principles of both Kaizen and PDCA to achieve their improvement goals. Through the synergy of these methodologies, organizations can cultivate a robust culture of continuous improvement, driving efficiency and fostering sustainable success [14].

2.4.2 The 5S

5S is a systematic approach that helps to organize a workplace for increasing efficiency and reduce wasting of productivity by providing an organized safe environment [15]. As a key component of the Kaizen philosophy [2.4.1], 5S promotes the concept of "transformation for improvement" and aligns closely with the principles of Total Quality Management (TQM). It serves as an initial Lean method that encourages the application of Lean techniques to enhance organizational performance.
5S is a progressive initiative that contributes to creating a higher standard of the work environment, fostering a sense of responsibility and commitment among team members, which ultimately results in organized and efficient workspaces. Improved equipment reliability and reduced work time enhance productivity, streamline workspace organization and maintenance, and lead to cost reductions. Furthermore, the 5S methodology has been shown to elevate employee self-esteem and strengthen commitment, contributing to a more engaged and motivated workforce.

5S is a way to improve the performance and to organize the whole system, which has been used first time by Japanese [16].
It comes from five Japanese words start with S, which is translated into English words to give the best explanation for them:

1. **Seiri or Sort:** this step involves separating necessary tools and materials from unnecessary ones, eliminating everything that is not essential to the work process. The goal is to reduce clutter and focus only on what adds value.

2. **Seiton or Set in Order/Straighten:** it focuses on organizing tools, materials, and equipment so that they are easily accessible and usable. Everything should have a designated place, which helps streamline the workflow and minimize time lost searching for tools.

3. **Seiso or Shine/Sweep:** this step entails regularly cleaning the workspace and equipment to ensure they are in good condition and functioning properly. A clean workspace helps maintain efficiency and prevents potential issues.

4. **Seiketsu or Standardize:** standardization involves creating rules and procedures to maintain the level of order, organization, and cleanliness achieved through the first three steps. This ensures that the best practices are upheld over time.

5. **Shitsuke or Sustain/Self-discipline:** the final step is about discipline and maintaining the improvements achieved through continuous effort. It requires everyone in the organization to be committed to following the 5S principles as a daily habit and part of the company culture.

Figure 2.11: The 5S

The next image (2.12) illustrates the transformation of a workspace before and after applying the 5S methodology. In the **Before** picture, the workspace is cluttered with scattered items, leading to inefficiency, wasted time, and potential safety issues. This disorganization reflects the presence of waste (muda) [2.3.1], as workers would need to search for tools and materials. In the **After** image, the workspace is organized, clean, and free of unnecessary items. Essential tools are neatly stored in designated locations, making them easily accessible.

Figure 2.12: Before and after implementing the 5S

This improvement demonstrates the effectiveness of 5S principles **Sort, Set in Order, Shine, Standardize, and Sustain** in reducing waste, improving workflow, and creating a safer, more productive work environment. The result is a more efficient, lean operation where workers can perform tasks with fewer interruptions and less wasted effort.

2.4.3 Total Productive Maintenance

In the pursuit of operational excellence, the implementation of Lean Manufacturing (LM) and tools such as the Just-in-Time (JIT) system from the Toyota Production System (TPS) [2.2] places immense pressure on machine reliability. This is particularly evident in the demand for zero inventories, zero breakdowns, and the elimination of non-value-added activities.

Total Productive Maintenance (TPM) emerges as a critical Lean Manufacturing tool that focuses on optimizing machine and process productivity, serving as a fundamental pillar in the continuous improvement process. TPM is an innovative maintenance approach designed to eliminate equipment failures and breakdowns, optimize equipment effectiveness, and promote autonomous maintenance by operators [17]. This approach extends beyond traditional maintenance models by involving all employees in daily activities, fostering a culture of continuous improvement.
TPM's emphasis on proactive and preventive measures ensures that operators take ownership of machine maintenance, helping to reduce unexpected downtime and inefficiencies.

The significant contribution of Lean Manufacturing implementation in improving business performance is through the elimination of waste (7 wastes) [2.3]. The amount of waste produced in the manufacturing process has a strong relationship with the performance of the machine or equipment. Strategic maintenance management such as TPM is thus very necessary to ensure the success of Lean Production [17].

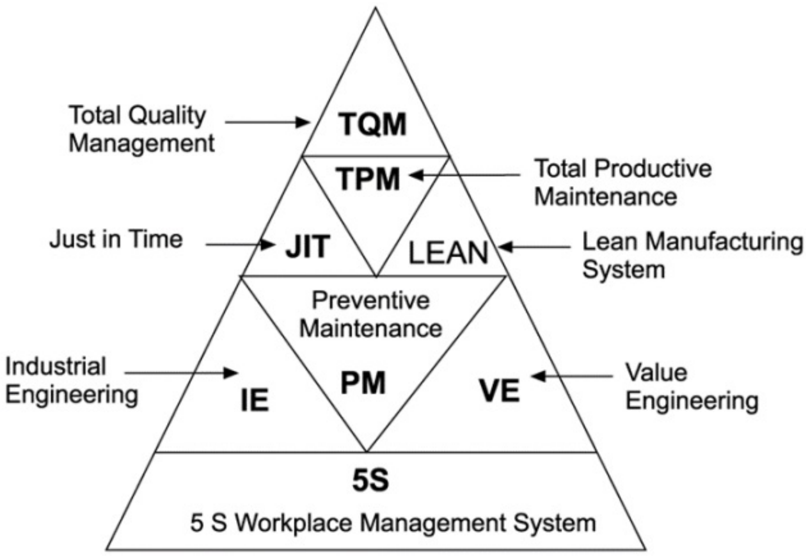


Figure 2.13: Relationship between TPM, LM and others philosophies

This figure 2.13 illustrates the close relationship between various manufacturing philosophies, showing that TPM is a cornerstone for most Lean Manufacturing strategies. Its significant contribution lies in its ability to support the successful implementation of Lean by ensuring that machinery and processes run smoothly, reducing downtime and eliminating production inefficiencies [17].

2.4.4 Single Minute Exchange of Die

Lean Manufacturing offers the proper tools in order to reduce the waste inside and between different processes, being able to increase the value of the product. The waste elimination principle is to minimize the NVA and focus on the VA activities. Among various lean manufacturing tools, **Single Minute Exchange of Dies (SMED)** is particularly effective for reducing inventory levels and, more importantly, minimizing changeover times (C/O) during production, especially when transitioning between different batches, products, or machine setups. SMED is a tool developed by Shingo as a proposal to reduce bottlenecks in Toyota [18], and focuses on converting internal setup activities (those requiring the machine to be stopped) into external ones (which can be performed while the machine is still running) and streamlining the remaining internal steps [19].

Shingo bases his method on categorizing all setup activities into internal and external ones: with internal setup activities being ones that can only be performed when the machine is shut down, and external setup being those that can be conducted during the normal operation of the machine while it is still running [18].
SMED methodology is formed by four single stages illustrated in the next image (2.14):

1. **Separate Internal and External Setup Activities:** the first step in SMED is to clearly distinguish between these two types of activities. By identifying and separating them, you can shift as many internal activities as possible to external ones, minimizing downtime.

2. **Convert Internal Setup to External Setup:** this is done by preparing everything that can be handled while the machine is still operating before the actual changeover starts. This conversion reduces the amount of time the machine remains idle during changeover by doing necessary preparations in parallel with ongoing production.

3. **Streamline Internal Setup:** this involves eliminating unnecessary movements, using quick-release mechanisms, or standardizing and simplifying tools or adjustments to further minimize the duration of internal setup activities, ensuring they are done in the shortest possible time.

4. **Continuous Improvement (Kaizen):** the final step is to continuously improve the changeover process through Kaizen [2.4.1].

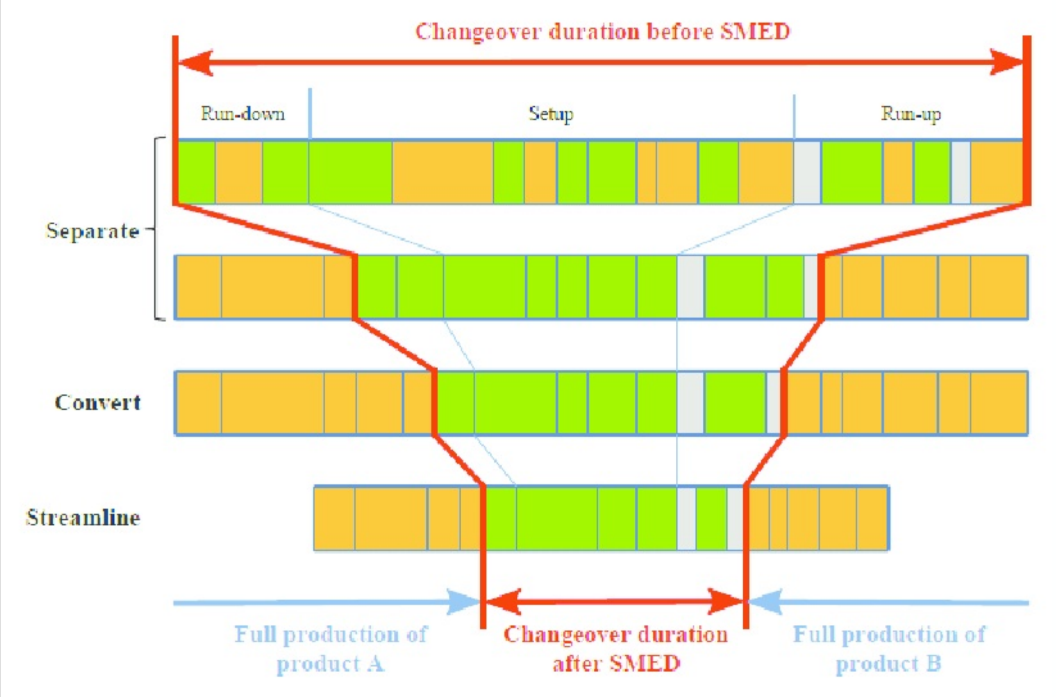


Figure 2.14: The four steps of SMED methodology

Implementing SMED lead to many advantages, as reduces changeover times, lowers inventory levels, increases production flexibility, improves machine utilization, and reduces overall costs, leading to a more efficient and responsive manufacturing process.

2.4.5 Six Sigma

One of the most effective methodologies for achieving this high level of quality is Six Sigma, a system that has been implemented by leading organizations worldwide over the last decade. Six Sigma helps organizations increase profitability and growth by enhancing the efficiency and consistency of their processes. The focus of Six Sigma is on improving quality by reducing process variability and eliminating errors, with a goal of achieving near-perfect output. It employs a data-driven approach to identify defects and ensure continuous process improvement through statistical tools that monitor performance [20].

However, while Six Sigma excels in addressing quality, it often falls short in terms of improving process speed. This gap is where Lean Management comes into play. Unlike Six Sigma, which focuses primarily on reducing variability, Lean aims to streamline operations by identifying and removing non-value-added activities (waste), thus optimizing the use of resources, including human, material, and capital. Lean Management ensures that products reach customers on time while maximizing efficiency.

The complementary nature of Lean Management and Six Sigma has led to the development of Lean Six Sigma, a hybrid approach that combines the strengths of both methodologies. Lean addresses inefficiencies and speeds up processes by eliminating waste, while Six Sigma ensures that quality is maintained by reducing errors and process variations. Together, these methodologies provide a powerful framework for improving both the speed and quality of operations, driving enhanced performance across all areas of the organization.

2.5 Push and Pull flow system

The objective of lean manufacturing, as we have said, is to improve productivity and reduce waste and costs. One of the key steps in achieving this is to limit inventory levels by moving towards just-in-time principles and implementing pull control systems.
However, in case of unexpected disruptions such as fluctuation in demand, rush orders, machine breakdowns and quality loss problems, low inventory can lead to reductions in performance and delivery delays [21]. A further issue closely connected to the inventory levels is the selection of Pull versus Push control principles.

Companies often feel that they must choose between employing a push or pull replenishment strategy.
The terms **Push** and **Pull** have been used to describe a wide variety of manufacturing environments. The distinction refers to a specific attribute which can be identified by observing the mechanisms for controlling material flow on the factory floor and a specific policy for the management of inventories and production schedule [22].
They both have advantages and drawbacks.

2.5.1 Push system

A Push approach to production management is the most conventional. In the Push-type system, parts are released to the next station as quickly as possible to avoid starvation at the downstream stations.
Information regarding demand forecasts or customer orders for end products are processed to all production stages. Usually, production orders are released at the first stage and then the order is "pushed" through the production system [22].
This characteristic enables the system to reduce delivery lead time since many semi-finished or finished products are available at the time of order. Variations of demand may not cause problems because inventory is kept at each station [21].

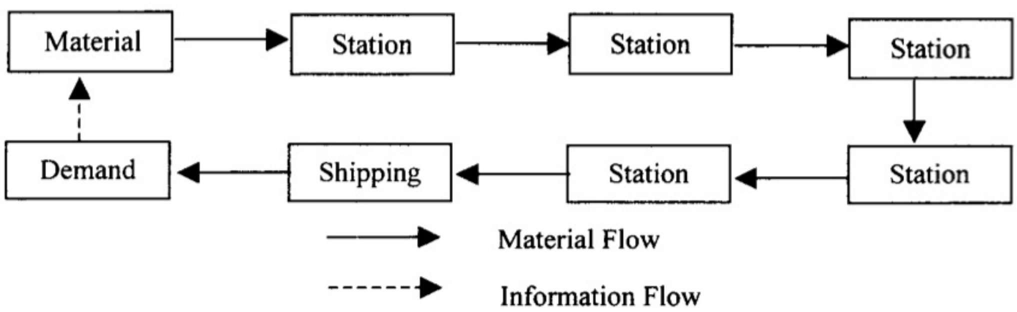


Figure 2.15: Representation of Push system

However, a Push system can lead to many problems: high inventory holding costs, low inventory turns, high risk of stock obsolescence and reduced service levels, resulting in low profits [21].

2.5.2 Pull system

The Pull-type system drives production based upon customer demand. Instead of pushing products as allowed by production capacity, in the Pull principle, inventory levels are limited and controlled by order requirement signals (or kanbans) [21].

In a Pull system, information about customer orders (and forecasts) is processed to the finished goods inventory or to the last production stage. If demand cannot be satisfied directly, the stage will order and withdraw parts from the buffer storage of the preceding stage, and so on. Thus, a serial ordering system of successive production orders is incurred [22].

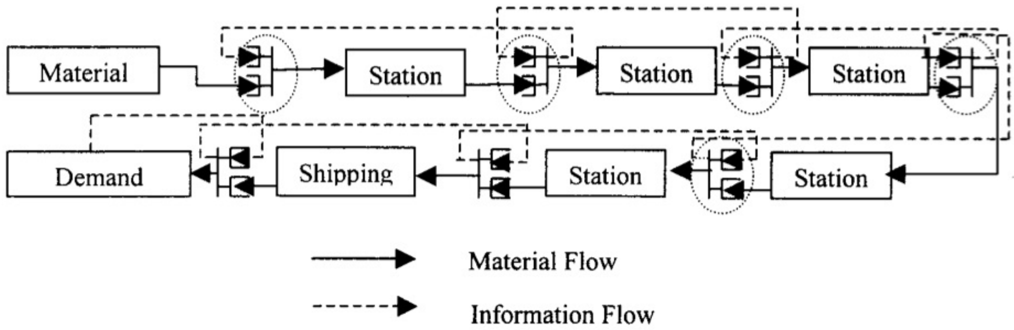


Figure 2.16: Representation of Pull system

While there are many advantages to the Pull approach such as high service levels, decreased inventory level and, therefore, low carrying costs, there are some disadvantages. Pull system faces difficulties to satisfy demand variations due to low levels of inventory [21].

2.5.3 Mixed Push and Pull system

In a mixed Push-Pull system, the integration of both push and pull principles is applied throughout the production process. Certain parts of the system operate under the Push mechanism, while others follow the Pull approach.

This mixed system is typically designed in relation to bottleneck resources, where the bottleneck represents the stage with the longest cycle time compared to other stages [22].
In the earlier stages, which precede the bottleneck, the production process can generate a surplus of work-in-process (WIP) inventory. To manage this, a Pull system is implemented to control the amount of WIP in these stages, ensuring that production is only initiated based on demand from downstream processes. Conversely, in the stages following the bottleneck, the process is typically managed through a

push system, as the output of the bottleneck dictates the pace of production for these subsequent stages.

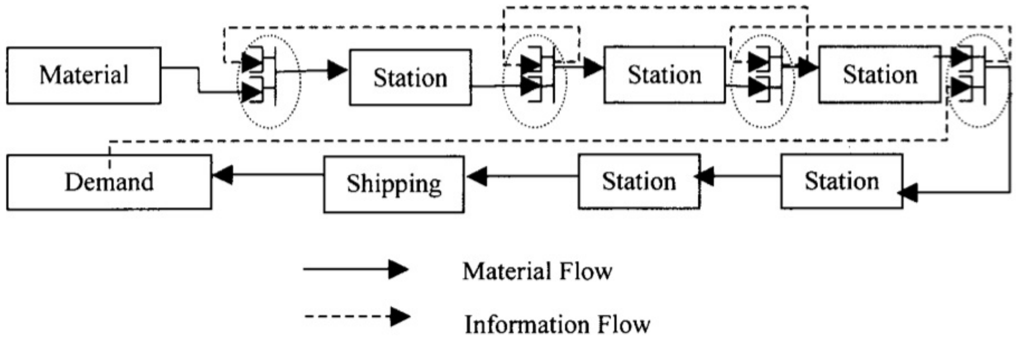


Figure 2.17: Representation of mixed Push and Pull system

In such a mixed Push-Pull system, customer orders or demand are directed to the bottleneck stage. If the bottleneck can satisfy the demand, production continues forward through to the final stages. If demand exceeds capacity, the bottleneck stage will trigger orders and withdrawals from buffer inventories in the preceding stages, ensuring a smoother flow of materials throughout the process [22].
This integrated approach helps optimize production flow, reduce excess inventory, and better manage bottleneck constraints within the system.

2.6 Industry 4.0: The integration of Lean with Digital Technologies

The Fourth Industrial Revolution, commonly referred to as Industry 4.0, represents a significant evolution in the manufacturing environment, building upon the advances introduced by the first three industrial revolutions. Similar to Lean Manufacturing, Industry 4.0 is not solely focused on advanced technological tools but also incorporates a broader management vision aimed at transforming manufacturing systems [23]. At the core of Industry 4.0 is the concept of the Smart Factory, a manufacturing paradigm that blends cutting-edge technologies with strategic business models, management adjustments, and process innovations.

The foundational vision of Industry 4.0, as outlined in its initial reports, is to implement a smart, fully connected factory where manufacturing processes are optimized in real-time through the integration of Cyber-Physical Systems (CPS). Cyber-Physical Systems are defined as integrations of computational elements and physical processes, in which embedded computers and networks monitor and control these processes, often in real-time. This real-time, reciprocal interaction between machines, systems, and data-driven insights enables factories to operate with a higher degree of autonomy, precision, and adaptability, which is considered essential for the goals of Industry 4.0 [23].

The implementation of CPS in Industry 4.0 enables manufacturers to create smarter, more efficient production systems that can self-monitor, self-diagnose, and self-optimize, reducing downtime and increasing productivity. By integrating digital and physical systems, Industry 4.0 provides the flexibility to quickly adapt to market demand and customer preferences, transforming how organizations manage and optimize their entire production ecosystems.

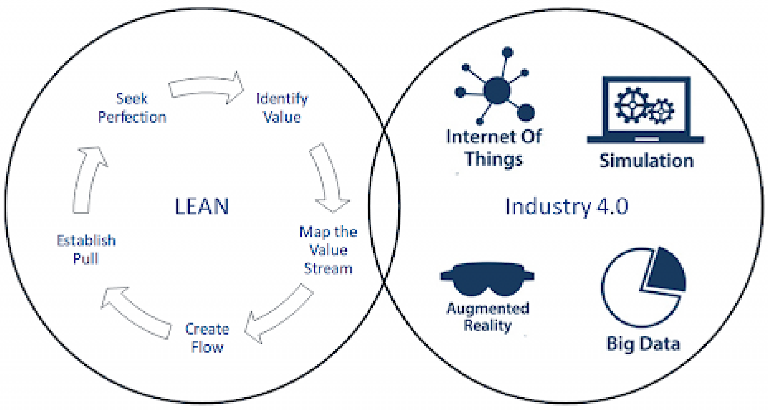


Figure 2.18: Industry 4.0 and Lean Management

Chapter 3

VALMEX S.p.A. and the Production of Heat Exchangers

3.1 History of VALMEX S.p.A.

Valmex S.p.A. is a global benchmark in the production of heat exchangers made from copper, aluminum, and steel for wall-mounted boilers.
The company's roots trace back to the former Meccanica Valle Metauro (MVM) division, founded in 1969 by Eng. Severino Capodagli, the current president of the group. Initially focused on the cold stamping of metal components, MVM marked its entry into the heat exchanger sector in 1980, becoming a pioneer in producing exchangers for wall-mounted boilers.

Valmex S.p.A. was established in 1999 as a result of the divestiture of a business unit from M.V.M. S.r.l., specifically the production of heat exchangers. This transition allowed Valmex to acquire valuable expertise in the gas boiler heat exchanger market, developed since 1983. The increasing demand for thermal systems with higher efficiency, alongside stricter pollution regulations imposed by new EU laws, drove the investment in new technologies and product types, including aluminum—an ideal material known for its corrosion resistance against combustion fumes, thereby enhancing boiler efficiency.

Figure 3.1: Valemx logo

In August 2013, M.V.M. S.r.l. was incorporated into Valmex, establishing a significant technological hub capable of producing a wide range of products and equipment. Around the same time, Valmex acquired the entire share capital of Realmec S.r.l., a mold and equipment manufacturer that complements the company's activities, particularly in equipment construction and prototyping.

In 2016, Valmex expanded its covered area by approximately 9,000 square meters, which led to the establishment and strengthening of its flagship production department: the Circond facility, dedicated to manufacturing high-end condensing heat exchangers with single-tube coils for the high-efficiency boiler market. Over the years, Valmex has strengthened its organizational structure through a new logistical and production organization, ensuring excellent service performance for its customers. From late 2016 to the end of 2017, specialized personnel were hired to bolster both the technical and operational/logistical areas, especially in the steel department. In 2017, leveraging its technological background, Valmex implemented several improvements in its stamping division, enhancing equipment and work environments and refining its organizational structure with the aim of reducing costs and improving performance. The future goals for the stamping division are to consolidate its position as a reference point in its operational area by focusing on highly qualified products and processes, as well as specializing in the production of essential components for heat exchanger manufacturing.

At the end of 2021, Realmec was integrated as a detached department of the group, ceasing its corporate identity. As of January 1, 2022, the facility in which it operates became a production branch of the Valmex group, focusing on both mold production and the manufacturing of special stainless steel heat exchangers—custom products for the American market with lower volumes compared to standard stainless steel exchangers.

Throughout the year, Valmex rented a new 8,000 square meter building, designated partly for warehouse space and partly for stainless steel production.
Today, Valmex employs approximately 400 people and generates an annual turnover exceeding one hundred million euros, thanks to a strong presence in global markets, particularly in Turkey, Northern Europe, Eastern Europe, and the United States. The company operates in three main production facilities located in Cartoceto (PU), covering over 22,000 square meters, and an additional 5,000 square meter facility in Montefelcino (PU), acquired with Realmec. Furthermore, Valmex has extended its international presence with a production facility in Kunshan, near Shanghai, thereby reinforcing its foothold in the Asian market. Valmex's growth is closely linked to ongoing investments in technological innovation and its ability to respond to the demands of global markets.

Figure 3.2: Photo Valmex

3.2 Products and processes: the heat exchanger production analysis

VALMEX S.p.A. specializes in the production of customized heat exchangers, offering a wide range of products tailored to client specifications. In its dedicated heat exchanger department, the company is capable of producing:

- Aluminum Heat Exchangers
- Copper Recuperators
- Stainless steel Heat Exchangers

The products provided by VALMEX S.p.A. are supplied to boiler manufacturers worldwide, including the American market, following the achievement of ASME certification in 2018.
The decision to produce on a made-to-order basis is a strategic choice for VALMEX S.p.A., as each product is defined according to client specifications and adapted to the capabilities of the production process. Therefore, based on the requirements specified by the client, VALMEX S.p.A. prepares all the necessary documentation for product industrialization, ensuring a customized and high-quality service.

3.2.1 Stamping department

In the stamping department, VALMEX S.p.A. specializes in the cold processing of sheet metal made from various ferrous and non-ferrous materials, including mild steels, coated or stainless steels, copper, and aluminum.
Within the stamping department, VALMEX S.p.A. processes cold sheet metal, starting from coils, squares, or strips, using both automatic and manual methods. The company utilizes mechanical and hydraulic presses with capacities ranging from 6 to 1.250 tons, ensuring a versatile and efficient production process.

The stamped components find extensive applications across various industries. For high-volume production, VALMEX employs transfer molds and automatic or combined progressive dies, utilizing sheets cut to size. In contrast, for smaller series, block molds are used, which require pre-sheared raw materials.
The complete processing cycle for printed products consists of:

- Special moulding.
- Rivet assembly (when required).
- Surface treatment: zinc, geomet, zinc nickel, varnishing (when required).
- Heat treatment: remediation, carbonitrification.
- Processing: Bursting, brushing (when required).

3.2.2 Department of exchangers

The heat exchanger department can be divided into 3 main families:

- Copper
- Aluminum
- Stainless steel

These material categories are crucial in meeting the diverse demands of the global market, as each offers specific advantages depending on the application and customer requirements.
In the following paragraphs will be explained the characteristics and functional properties of each exchanger as well as the production processes with the related machinery to produce the finished component.

Copper Recuperators

Copper heat exchangers are known for their excellent thermal conductivity and durability, making them ideal for a wide range of heating systems.
In the copper exchanger department, mechanical processing is carried out in principle, consisting of cold processing of copper tubes and fins; a subsequent assembly phase, in which the fin exchanger is physically completed, heads, curves, fittings and brazing. It follows a thermal phase, inside controlled atmosphere ovens, in which the brazing material is melted and makes the different components a single body. The heat exchangers are tested to 100% and then sandblasted, washed, painted, packaged and shipped.
The complete machining cycle for copper exchangers consists of:

- Sheet metal forming;
- Stacking of slats;
- Mounting terminal fins;
- Fitting of joints, curves and manifolds;
- Continuous furnace H2-N2 brazing;
- 100% leak-proof testing
- Coating with silicone resins.

The main machines and plants included in the production cycle for copper exchangers are:

- Barrel washer;

- Automatic pipe cutting machine;
- Mechanical press for forming oval tubes;
- Stacking machines: hydraulic presses;
- Hydraulic assembly machines;
- Brazing ovens;
- Air and helium pressure drop testing machines;
- Sandblasting plant;
- Paint system;
- Calibration machines fittings.

Aluminum Heat Exchangers

Aluminum heat exchangers are lightweight and are specifically resistant to the acidic corrosion caused by combustion products, such as condensate (this characteristic makes them suitable for use in both condensing and semi-condensing boilers), and are particularly suited for systems requiring high efficiency and reduced weight.
In the boiler exchange department, first of all the assembly phase is carried out, in which the brazing package of the exchanger is physically completed.
A second thermal phase, inside controlled atmosphere ovens, in which the filler material is laminated as a film on the surface of the base material, melting, making the different components into a single body. Finally, the final stage of quality control, testing and packaging of the exchanger.

Stainless steel Heat Exchangers

Stainless steel heat exchangers represent the latest generation of products, specifically designed for condensing boilers, offering superior resistance to high temperatures and corrosive environments, while also ensuring extended product longevity. The heat exchanger in stainless steel is the flagship product of the company, and an entire department has been developed for its production.

The process begins with the creation of a tube, which is manufactured internally from coils. Semi-automatic lines form the tube, weld it, and subject it to an annealing heat treatment when is required. Afterward, the tube is cold-formed to create a coil (the core of the heat exchanger). This coil is then flared to form the connections for the boiler pipes directly from the tube.
The semi-finished product is first 100% tested and then is washed and dried to remove oils and residues from the previous operations. At this stage, the coil is assembled with all other components to complete the heat exchanger (some components are

purchased, while others are produced internally via the stamping process) on a robotic assembly line. The product undergoes in-line testing and is either packed immediately or finished with customized accessories (such as burners, which are either assembled in-house with semi-automatic lines or procured as complete components) to meet the specific needs of various clients.
The main equipment used in this production cycle includes:

- Tube production lines;
- Tube bending machines;
- Socketing machines;
- Air transport plant;
- Washing and drying system;
- Robotic assembly and testing lines;
- Burner assembly line;
- Pressure loss testing machines.

3.3 Circond Monotermic: a heat exchanger in stainless steel

The **"Circond Monotermic"** (in the image 3.3) is an integrated and compact heat exchanger, engineered around a simple yet highly efficient oval-section stainless steel coil. This design allows for effective thermal transfer within a minimal space.
The heat exchanger is composed of three key sections: a combustion chamber, a condensing zone, and a separating disc. The metallic disc is insulated and protected using ceramic silicon fiber, effectively separating the combustion chamber from the condensing zone. This insulation plays a critical role in optimizing the heat exchange process, ensuring high performance in condensing applications.

The unique combination of these elements allows the Circond Monotermic to achieve superior thermal efficiency and durability in high-demand settings, making it ideal for modern high-efficiency gas boilers.
Key advantages include:

- **Compact:** its streamlined structure makes it easy to install in a variety of applications, particularly in space-constrained environments.
- **Easy interchangeability:** the modular design facilitates quick and efficient replacement or modification, making it adaptable to different system requirements.
- **Complete range for domestic applications:** the "Circond" heat exchanger is available in a variety of models, making it suitable for a wide spectrum of domestic heating applications (table 3.1).
- **Best performance and high reliability:** engineered for superior thermal performance and long-term reliability, the heat exchanger ensures efficient operation and reduced maintenance.
- **Modular for different outputs:** designed to accommodate diverse energy output needs, the heat exchanger is adaptable for use in systems with varying power requirements.

Figure 3.3: Picture of the heat exchanger **Circond Monotermic**

3.3.1 Product description

The Circond Monothermic heat exchanger features several key interfaces, which are critical to its integration and operation within heating systems.
These interfaces, all represented in the pictures (3.4) and (3.5), include:

- **Water inlet and outlet connections:** the points of connection for the system's water supply, allowing for efficient heat exchange.
- **Fixing point for assembly:** a dedicated interface to securely mount the heat exchanger during installation.
- **Flue gas outlet connection:** this outlet ensures the safe expulsion of exhaust gases, optimizing the combustion process.
- **Flue gas probe connection:** this interface ensures accurate measurement of exhaust gas composition.
- **Condensate drain connection:** provides an outlet for the condensate produced during the heat exchange process.
- **Burner door interface:** the designated connection point for the burner door, enabling easy access for maintenance and operational adjustments.

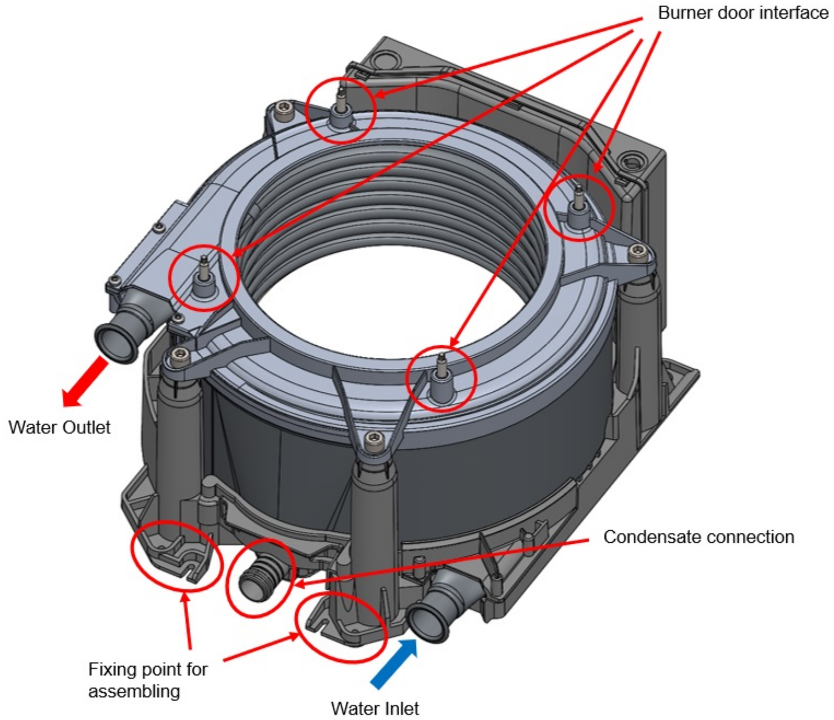


Figure 3.4: First interface **Circond Monotermic**

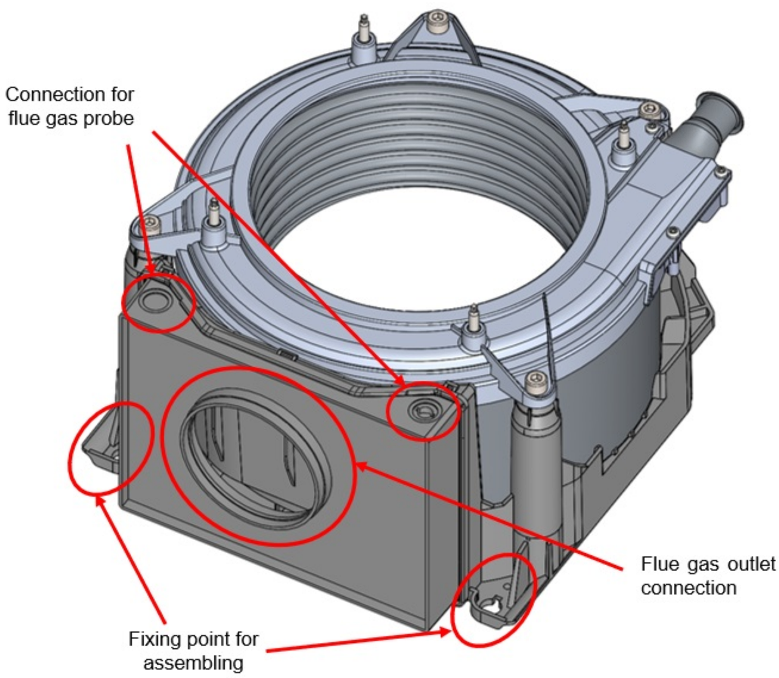


Figure 3.5: Second interface **Circond Monotermic**

3.3.2 Product range and main dimensions

The differences between the models are primarily related to the number of coil windings, which directly affects the heat transfer capacity and the external dimensions, as it's possible notice in the next image (3.6).

Figure 3.6: Comparison of two different exchangers

As illustrated in the table below in table (3.1) and in the figure (3.7), each model features varying depths (dimension A), water connection distances (dimension B), and weights. These differences ensure that each model is optimized for specific performance and installation requirements.

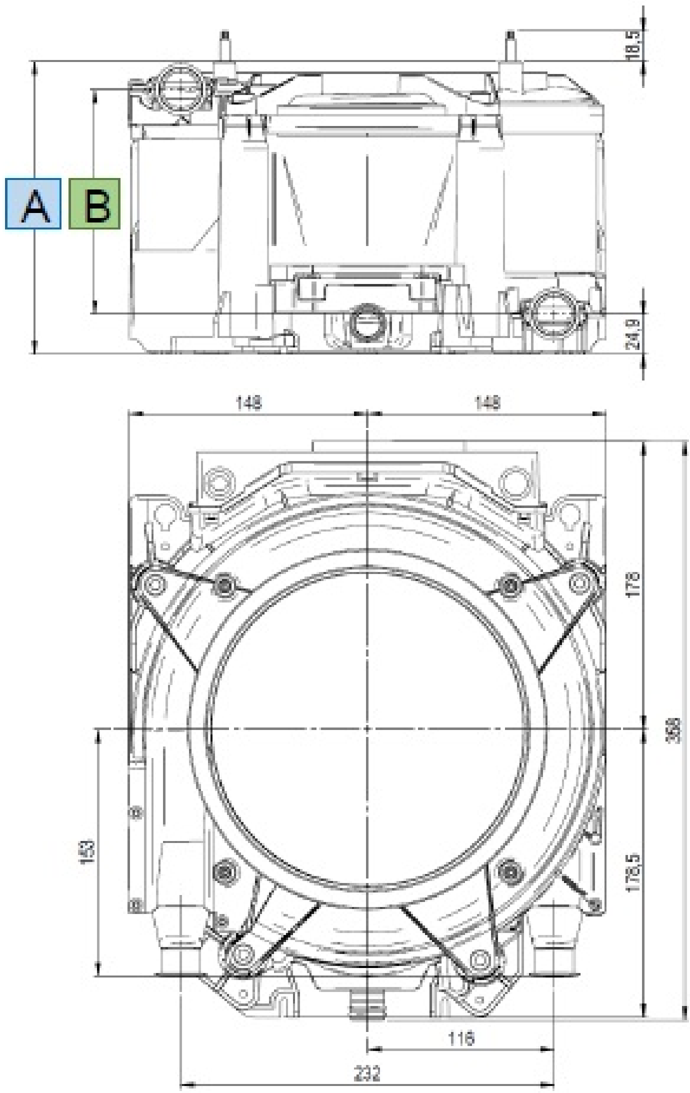


Figure 3.7: Difference in height and in the distance of water connection between two exchangers

The table (3.1) moreover, outlines the main technical specifications of the spiral heat exchanger models produced by VALMEX S.p.A.
The models differ based on the number of coils, which affects the external dimensions and energy performance, thus catering to various application requirements.
Specifically, the table provides the nominal thermal power for both the Central Heating (CH) and Domestic Hot Water (DHW) circuits, as well as the efficiency values, all compliant with ErP standards.
Additionally, the table highlights the key dimensions of the heat exchangers, the water and flue gas connections, with a note on customization possibilities to meet specific customer requirements.

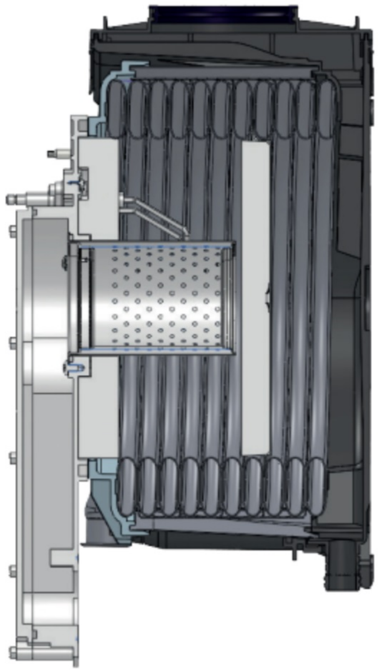
Heat exchanger model [number of turns]	8.5	10.5	11.5	13.5	15.5	17.5
Max Q input (CH mode) [kW]	21	24	27	28	32	45
Max Q input (DHW mode) [kW]	24	28	33	35	40	48
Efficiency [%]	ErP compliant					
Dimensions						
Width* [mm]	295.6					
Height* [mm]	361.3					
Depth* (A) [mm]	172	182	195	221	247	272
Water connections [mm]	Ø 22.6 rapid					
Distance between water connection (B) [mm]	232x113	232x139	232x152	232x178	232x204	232x230
Smoke outlet connection [mm]	Ø 60 or Ø 80					
*The location can be customized according to customer's requirements						

Table 3.1: Technical characteristics of heat exchanger models

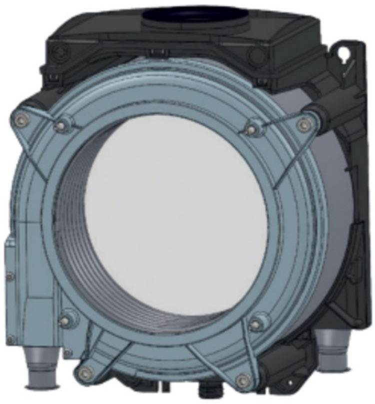
3.3.3 Advantages of a single coil heat exchangers

A single-coil heat exchanger offers numerous technical and operational advantages, making it an optimal choice for advanced applications.
The following are the primary benefits:

- **Self-cleaning:** the single-coil configuration minimizes the accumulation of impurities within the system, thereby reducing the need for frequent maintenance and extending the overall lifespan of the equipment.
- **Minimal number of components:** the simplified design, with a reduced number of parts, enhances system reliability and facilitates both assembly and maintenance processes.
- **High efficiency and robustness:** due to its compact and optimized structure, the single-coil heat exchanger ensures high thermal and mechanical performance, making it particularly suitable for applications requiring durability and long-term resistance.
- **Stainless steel construction:** the use of stainless steel provides excellent corrosion resistance and increases the lifespan of the heat exchanger, even in harsh operating environments.
- **No welding processes:** the absence of welding during the manufacturing process reduces the risk of structural defects and enhances the overall integrity of the component, improving both performance and safety.



(a) Section of exchanger



(b) Image of exchanger

Figure 3.8: Graphic visualization of exchanger

3.3.4 Functional principles of Circond Monotermic

The Circond 1.0 heat exchanger operates through a carefully designed integration of its core components, which work together to achieve optimal thermal efficiency.
The following picture (3.9) provides an exploded view of the heat exchanger, highlighting its key functional elements:

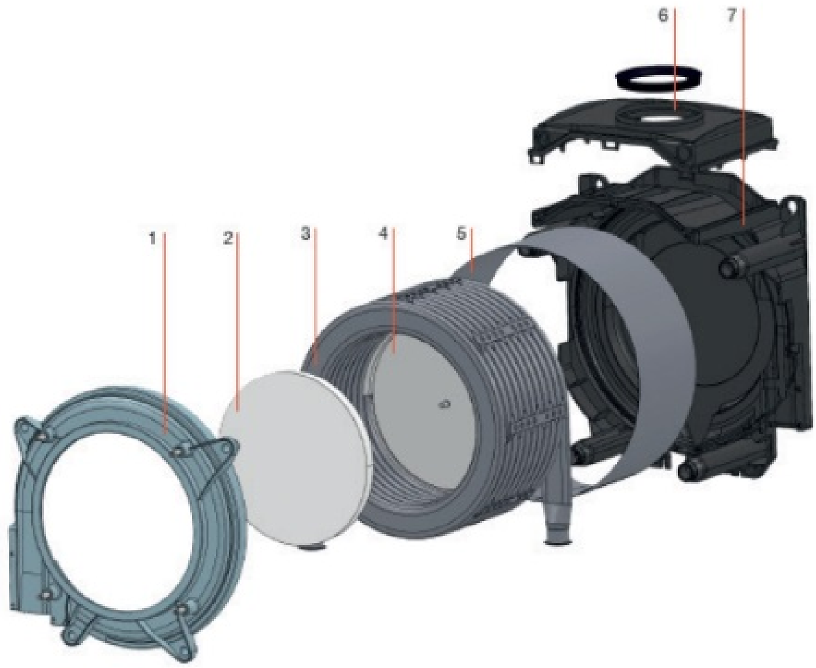


Figure 3.9: Exploded figure of **Circond 1.0**

In the preceding figure, the numbers of components refer to:

1. **Frontal cover:** this cover seals the combustion chamber, ensuring airtightness and facilitating heat retention. It also provides easy access to internal components for maintenance, contributing to the system's long-term operational reliability;

2. **Divider plate insulation:** the insulation around the divider plate ensures thermal separation between the high-temperature and low-temperature zones within the heat exchanger;

3. **Coil:** the stainless-steel coil is the primary element through which heat is transferred from the combustion gases to the circulating water. It ensures both high thermal conductivity and resistance to corrosion;

4. **Divider plate:** this metal plate separates the combustion chamber from the condensing section of the heat exchanger. It allows the system to maintain distinct thermal zones, optimizing the efficiency of the condensation process and facilitating the efficient extraction of heat from the exhaust gases;

5. **Coil casing:** the casing surrounds the heat exchanger coil, supporting the structure and protecting it from external damage. It also helps maintain the correct positioning of the coil for optimal heat transfer.

6. **Casing top:** the top section of the casing acts as a closure for the upper part of the heat exchanger and provides access for maintenance and inspection. Its secure fitting ensures the heat exchanger remains well-insulated and operationally stable during combustion.

7. **Back casing:** the back section of the casing serves as the housing for the entire unit, ensuring the assembly remains stable and insulated from external environmental factors. It also supports the integration of additional components, such as the flue gas outlet and water inlet and outlet connections.

The next image (3.10) illustrates the working principle of the Circond Monothermic heat exchanger.

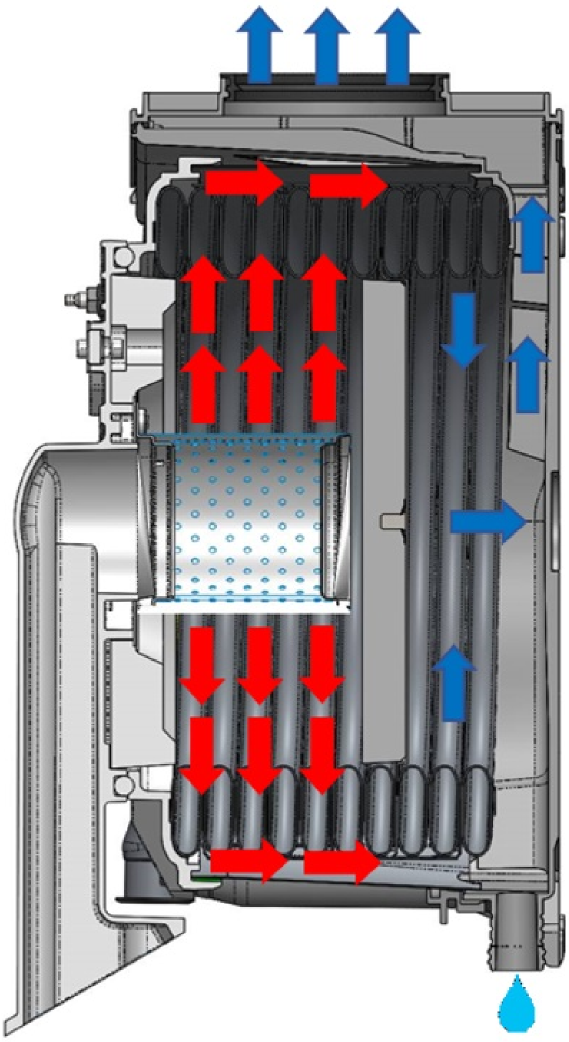


Figure 3.10: Heat and fume circuit

The structure of the heat exchanger ensures that the hot flue gases produced in the combustion chamber (represented with the red arrows) pass through the first set of coils before reaching the metallic disc, transferring high-temperature thermal energy to the outer shell. After that, the gases pass through the deflector and move through the final set of coils (represented with the blue arrows), enabling low-temperature heat exchange, which preheats the incoming water by condensing the exhaust gases.

The condensation, formed due to the significant drop in exhaust gas temperature, is collected at the lower part of the heat exchanger, while the remaining gases exit through the upper section. The metallic disc separates the combustion chamber from the condensing area, and its position can be adjusted a distinctive feature that ensures optimized heat exchange for each specific power output.

This unique characteristic affects both the exhaust gas pressure losses and the volume of condensation produced, directly influencing the overall efficiency of the heat exchanger.

3.3.5 Strong reliability and product validation and certification

The Circon Monotermic heat exchanger has undergone extensive testing and is built on a solid design concept, ensuring its durability and performance:

- **CFD Analysis:** Computational Fluid Dynamics (CFD) simulations to optimize the flow and thermal properties;
- **Robust Design Methodology:** a systematic approach to ensuring strength, stability, and functionality in various operating conditions;
- **Enhanced Efficiency:** designed to maximize thermal exchange with minimal energy loss.
- **Accelerated Lifetime Testing:** subjected to numerous cycles under critical conditions to validate longevity.
- **Field Reliability:** proven performance and durability in real-world applications.

Circond adheres to several important certifications and compliance standards that ensure the highest quality and safety in its manufacturing processes.
This Quality, Environment, and Safety Manual refers to the following standards:

- UNI EN ISO 9000:2015 - "Quality management systems – Fundamentals and vocabulary"
- UNI EN ISO 9001:2015 - "Quality management systems – Requirements"
- UNI EN ISO 9004:2018 - "Managing for the sustained success of an organization – A quality management approach"

- UNI EN ISO 14001:2015 - "Environmental management systems – Requirements with guidance for use"
- UNI EN ISO 14004:2016 - "Environmental management systems – General guidelines on principles, systems, and support techniques"
- UNI EN ISO 19011:2012 - "Guidelines for auditing management systems"
- UNI ISO 45001:2018 - "Occupational health and safety management systems – Requirements with guidance for use"
- ISO/IEC 27001:2017 - "Information security management systems"

3.4 Production processes of the Circond Monothermic

Up until now, we have discussed the characteristics of the heat exchanger; now I will now focus on the manufacturing processes that transform the raw material into the finished product.
To achieve this, the raw material, specifically the stainless steel coil, undergoes processing in three main stations within the Value Stream 1.0 (the following facilities have been considered for the heat exchanger under examination):

- **Tube Line 2**
- **Automatic Island 5**
- **Assembly Station 4**

3.4.1 Tube Line 2

The Tube Line 2 is the first processing plant in Circond Monotermic production.
In this plant the raw material in the form of stainless steel coils undergoes the transformations that create the first semi-finished product of the production line, we are talking about the steel tube.
The processing steps are as follows:

1. **Unwinder:** this machine unrolls the stainless steel coil, preparing it for further processing.
2. **TIG Welding:** this process involves Argon Inert Gas welding, used for high-quality, precise welds, used only for the start-end coil joints (as the process is continuous).
3. **Accumulation:** the machine temporarily stores the material to maintain a smooth flow in the production line.
4. **Scarfing:** the operation where material is shaved or cut off the surface to achieve the desired shape.
5. **First Forming:** initial shaping of the metal strip to begin creating the desired component structure.
6. **Laser Welding:** a high-precision welding process using lasers to join metal components.
7. **Deburring Machine:** removes any sharp edges or burrs left on the components after cutting or shaping.
8. **First Calibration:** ensures the product dimensions and tolerances are accurate after the initial forming stage.

9. **Reheating Furnace:** heats the metal components to make them easier to work with in the next process (used only when necessary, depending on the type of steel in use).

10. **Maintenance Oven:** keeps the material at a stable temperature before further processing.

11. **Cooling Furnace:** gradually cools the material after it has been heated and formed.

12. **Second Calibration:** a secondary step to ensure the product dimensions are precise after forming and cooling.

13. **Turk's Head Machine:** this machine applies final shaping, ensuring precision in diameter and roundness.

14. **Cutting Group:** cuts the material into the required lengths for assembly or final processing.

15. **Roller Path:** a series of rollers used to move the components efficiently along the production line.

16. **Bulk Unloading/Loading Line 2:** where the material is unloaded or loaded into bulk containers for transport or further processing.

17. **Line 2 Unloading:** teh last step removes components from Line 2 and carries them via overhead crane to the warehouse of the Automatic Island 5, preparing them for the next stage.

3.4.2 Automatic Island 5

The Automatic Island 5 is the station which transforms the tubes produced by the Tube Line 2 into coils. The production process is characterized by a high level of automation and precision.

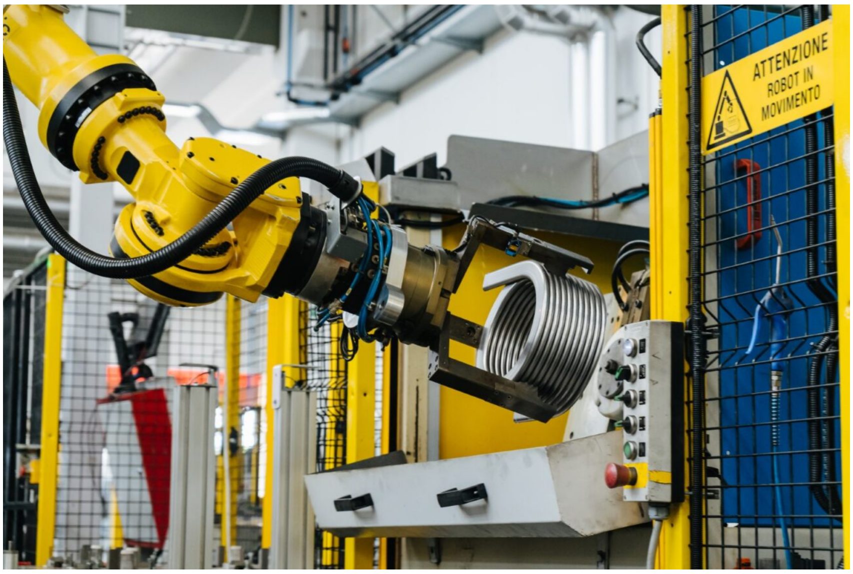


Figure 3.11: Picture of Automated Island 5

The production steps carried out on Automatic Island 5 are as follows:

1. **Loading Station 5:** the tube produced in the Tube Line 2 is automatically retrieved from storage and loaded to initiate the production process.

2. **Tube Bending Machine 5:** the stainless steel tube is bent into the desired shape, preparing it for subsequent manufacturing stages.

3. **End Connection Forming Machine 5:** the cups, essential metallic components for assembling coils, are shaped in this phase.

4. **Coil Testing Machine 5:** the coil undergoes air pressure decay test (water side testing) of 4 bar testing to ensure its quality and structural integrity. If the test fails, the coil is rejected; if it passes, the part is then washed.

5. **IFP Washing Machine 5:** after testing, the coil is cleaned to remove any impurities or residual materials from the manufacturing process.

6. **Robot Station 5:** robotic automation is employed for handling and moving components between different processing stages. The coil is loaded into pallets, awaiting transfer to the assembly warehouse.

3.4.3 Assembly Station 4

The assembly station 4, which is known as **CTF4** within the company, is the place in where are performed all the assembly steps necessary for the heat exchanger take place. The process is largely automated to ensure precision and efficiency throughout the production line.

Figure 3.12: Picture of CTF4

The steps necessary to make the exchanger starting to raw material and subassembly are listed in the Machine Ledger of the picture (3.13), and in the order are:

1. **Loading and Unloading (carico e scarico):** the initial step involves loading raw materials or components onto the production line, preparing them for further processing.

2. **Component Inspection (controllo componenti):** the components are checked to ensure they meet the required standards for further assembly.

3. **Plasma threatment (Plasmatura):** the process where parts undergo shaping or forming, essential for the subsequent assembly steps.

4. **Silicon application (siliconatura coperchio e fondo):** in this phase, the cover and bottom are coated and sealed using silicone to ensure airtight and secure assembly.

5. **Dividing Disk Assembly (assemblaggio disco divisorio)**: the dividing disk is assembled into the product to support structural integrity.

6. **Spacer Assembly (assemblaggio distanziali):** spacers are inserted between parts to maintain proper distance and alignment.

7. **Coil Casing Welding (saldatura virola):** welding of the "Coil casing" (metal ring or cylindrical part) is carried out to attach the parts securely.

8. **Coil Casing positioning (orientamento virola):** the Coil casing is oriented correctly to align with the assembly before proceeding to the next steps.

9. **Coil Positioning (posizionamento serpentina):** the coil is positioned accurately within the structure, crucial for the heat exchanger's functionality.
10. **Cover Positioning (posizionamento coperchio):** the cover is placed over the coil, preparing the assembly for final fastening;
11. **M8 Screwing (avvitatura M8):** screws (M8) are used to fasten various parts together, ensuring the product's stability.
12. **Insert Screwing and Sealing (Siliconatura e avvitatura inserti):** inserts are screwed into place, and silicone is applied to ensure proper sealing and insulation.
13. **Disk Insert and Screwing (avvitatura perni e inserimento disco):** the disk is inserted and screwed securely to complete the internal structure.
14. **Labeling (etichettatura):** the product is labeled for identification and traceability purposes.
15. **Disk Inspection (controllo disco):** a final inspection of the disk ensures that all components are correctly assembled and functioning as intended.
16. **Exchanger Fumes Testing (collaudo fumi scambiatore):** gas testing is performed to check the integrity and efficiency of the heat exchanger.
17. **Burner Assembly 1 (assemblaggio 1 bruciatore customized component):** the first stage of burner assembly is completed.
18. **Burner Assembly 2 (assemblaggio 2 bruciatore customized component):** the second stage of the burner assembly is carried out.
19. **Final Burner Assembly (assemblaggio bruciatore):** final assembly of the burner components is completed, ensuring the unit is ready for testing.
20. **Burner Fumes Testing (collaudo fumi bruciatore):** the burner is tested to ensure proper operation and efficiency.

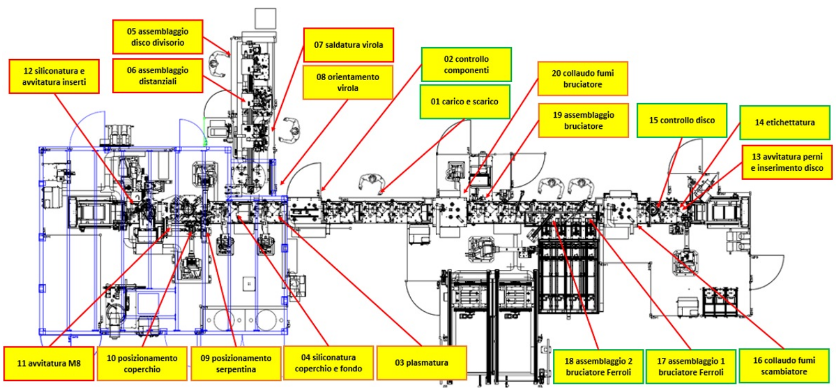


Figure 3.13: Machine Ledger CTF4

Chapter 4

Application of Lean Tools to the Production of Value Stream 1.0

During my internship, I have engaged directly with the processes and methodologies underpinning Lean Manufacturing principles, outlined in the chapter 2.
This chapter aims to illuminate how these principles were applied to optimize production workflows, enhance efficiency, and reduce waste within the context of the Value Stream Circond 1.0 (image 4.1). By analyzing the existing logistical frameworks and implementing Lean tools, I sought to identify key areas for improvement, ultimately contributing to a more streamlined and effective operational model.

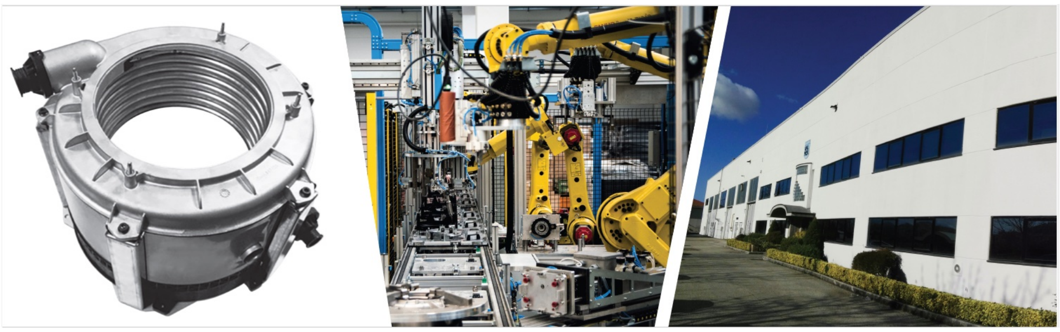


Figure 4.1: Photo of Value Stream Circond 1.0

As discussed in the previous paragraph [3.3], the production of heat exchangers within the Value Stream Circond 1.0 encompasses a range of sizes.
The most significant sizes are presented in the table below (4.1):

The purpose of my internship was to study and analyze the internal logistics flows by applying Lean principles within **Value Stream Circond 1.0 (VS 1.0)**, specifically focusing on the production of the heat exchanger **Riello 20 kW.**
This specific product was chosen for analysis to demonstrate how Lean methodologies can be effectively implemented to optimize production processes, reduce lead times, and enhance the quality of the final product. By examining the workflows, identifying value-added activities, and addressing sources of waste, I aimed to contribute to a more efficient operational framework that aligns with Lean Manufacturing principles.

Model / coils number	8,5	10,5	13,5	15,5
Max Q input (CH mode) [kW]	20	24	28	32
Max Q input (DHW mode) [kW]	24	28	35	40
Depth (A) [mm]	172	182	221	247
Distance between water connection (B) [mm]	113.3	139.2	177.9	203.7
Weight (without burner) [kg]	5.9	7.3	8.7	9.7

Table 4.1: Comparison of heat exchanger models based on coil number, maximum heat input, and physical dimensions.

This experience provided valuable insights into the real-world implications of Lean strategies and their potential to drive continuous improvement within manufacturing environments.

Building upon the Lean principles outlined in the previous chapters, I applied the tools of the **Spaghetti Chart** and the **Value Stream Map** [2.1.2] to effectively put these concepts into practice within Value Stream Circond 1.0.
This combination of tools allowed me to translate Lean principles into actionable strategies, ultimately enhancing operational efficiency and supporting the continuous improvement objectives of the project.

4.1 Analyzing workflow efficiency through spaghetti charts

The Spaghetti Chart, as we have mentioned in the paragraph [2.1.2], is a visual tool used in Lean Manufacturing to map the physical flow of materials, products, or personnel within a production process or workspace.
The main purpose of a Spaghetti Chart is to identify inefficiencies in movement within a given space, typically a manufacturing plant or operational environment.

To create a Spaghetti Chart, observers typically follow the actual path taken by a worker, material, or product throughout the production process, recording every movement on a floor plan.
The result is a diagram that maps out every step in the process, often revealing complex and convoluted routes that were previously unnoticed.

By comparing the current state (as-is) and the future state (to-be) processes, Spaghetti Charts help teams visualize how much unnecessary movement can be eliminated and where improvements can be made.

4.1.1 Spaghetti chart application in the production of the Riello 20 kW heat exchanger

The Spaghetti Chart was applied to the production process of the Riello 20 kW heat exchanger in Value Stream 1.0 to visually track the movement of materials and operators.

To draw the Spaghetti Chart, it was necessary to obtain the layout of the Value Stream 1.0 facility, represented in the image (4.2).

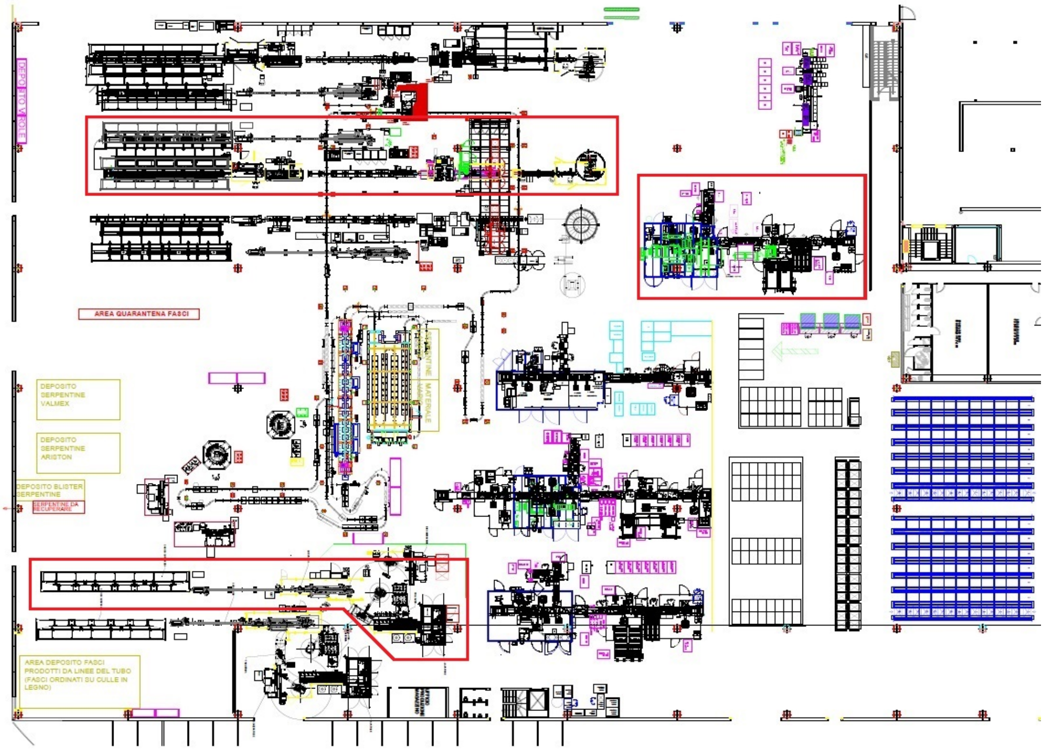


Figure 4.2: Layout of Value Stream Circond 1.0

This layout comprehensively represents the current state of Value Stream 1.0, in which the three plants under consideration [3.4] have been circled in red.
However, for the production of the Riello 20 kW heat exchanger, certain assumptions were made prior to developing the Spaghetti Chart.
Specifically, it was assumed that the production of the heat exchanger's coil would utilize the three facilities listed in the paragraph [3.4]:

- Tube Line 2
- Assembly Island 5
- CTF4

To effectively map the flow of all materials for the Riello 20 kW heat exchanger, it was essential to obtain the **Bill of Materials (BOM)** for the product.

The BOM is a comprehensive list that details all the components, subassemblies, and raw materials required to manufacture a product. It serves several critical purposes, including providing a clear overview of the necessary materials, facilitating inventory management, and enabling accurate cost estimation. By referencing the BOM, we were able to identify all the components involved in the production process, ensuring a thorough understanding of the material flow and allowing for a more precise analysis of the production system.

In the BOM are listed both the name and the code of the products. This provides a clear and detailed identification of each component, allowing for precise tracking and management throughout the production process.

The BOM of the Riello 20 kW is shown in the following image (4.3):

Articolo prodotto : A25102024801

Descrizione : ASM CIRC 252 AISI 441 W/BURNER WORGAS IN - 20 kW -1E - C772

Livello	Posiz.	Articolo	Descrizione
....5	10/ 11	A002088007	NASTRO - AISI 441 DIN 1.4509 - 2B OS
...4	10/ 9	A109039306	TUB.OV. - AISI 441 DIN 1.4509
..3	10/ 3	A110010153	SERPENTINA - AISI 441 - CIRC M VX
.2	10/ 1	A010010012	PORTA BRUCIATORE 1EL SAPCO - VX
.2	10/ 1	Y.21605	KIT 20kW RL
.2	10/ 5	A004017005	ASM FONDO+COPERCHIO RL FORO CHIUSO + SCUDO
.2	20/ 1	A010025008	ISOLANTE PORTA VALMEX - 1EL SAPCO
.2	20/ 4	A020001001	SILICONE
.2	30/ 1	A010015014	GUARNIZIONE PERIMETRALE PORTA VX
.2	30/ 4	A110020153	SERPENTINA 8,5 SP 0,7mm COLLAUDATA - AISI 441 - CIRC M VX
.2	40/ 1	A010015017	GUARNIZIONE ELETTRODO SAPCO
.2	40/ 2	A105051007	DISTANZIALE ELASTICO 7 ALETTE - CIRCOND MONO - AISI 441
.2	50/ 2	A010020010	GRUPPO ELETTRODO DI ACCENSIONE SAPCO KANTHAL APM E00402
.2	50/ 2	A105051008	DISTANZIALE ELASTICO 8 ALETTE - CIRCOND MONO - AISI 441
.2	60/ 1	A040002010	VITE TCEI M4X8 8.8 ISO 4762
.2	60/ 3	A105062004	DIVISORIO POST 1.0 BUGNE - STAMP+SALD - SP 0,7 mm - AISI 441
.2	70/ 1	A010015021	GUARNIZIONE BRUCIATORE PORTA VX
.2	70/ 4	A105008002	VIROLA 8 SPIRE LAVAT.C/SGOC+CAL -CIRC MONO -AISI 441
.2	80/ 1	A010005015	BRUCIATORE PREMIX - PRX0648 - BECKETT
.2	90/ 1	A004008002	INSERTO SGOCCIOLATOIO - CIRCOND MONO VX - PP 30% GF BLACK
.2	90/ 1	A040002019	VITE TORX TRIL T BOMB M5X10 T25 ISO 10664 UNI EN ISO 4042
.2	100/ 1	A040002005	VITE TX/R X TERMOPLA 1451 - 4x14 ZINC.B. A2K ISO4042
.2	100/ 2	0509009009	ADESIVO HOT-MELT S/100EXTRA - CREMA STICK Ø12x300(conf.10kg)
.2	110/ 1	A004007002	INSERTO TUBO FONDO POST - CIRCOND MONO VX - PP 30% GF BLACK
.2	120/ 1	A040002005	VITE TX/R X TERMOPLA 1451 - 4x14 ZINC.B. A2K ISO4042
.2	130/ 5	A004004014	COPERCHIO FRONT. - CIRCOND MONO VX - EN AB 47100
.2	140/ 2	A040002029	VITE TCEI - M8x30 8.8 - ISO4762 - ZINC B A2K ISO4042 593SA
.2	150/ 1	570818008C	DADO ESAG FLANG - FIL M8 - SPEC - 6S ZINC.B. A2K ISO4042
.2	160/ 1	A004006002	INSERTO TUBO COP. FRONT. - CIRCOND MONO VX - EN AB 47100
.2	170/ 2	A040002014	VITE TC/TX 20 AUTOFORM x AL - M4x14-12 ZINC.B. A3K ISO4042
.2	180/ 4	A013002007	DISCO ISOLANTE - D194,1 SP17,5 - ISOFRAX 120 CB
.2	190/ 4	A040001006	PERNO DOPPIO FILETTO 6x8 M6x18,5 ISO 4042
1	10/ 10	A210020252	CONDENSING CIRCULAR MONO HE AISI 441 8,5 RL
1	15/ 2	A150001013	BURNER ASSY VX 8,5 - 1EL K.APM
1	25/ 1	A040003006	DADO FLANG.ZIGR. - M6 DIN6923 ACCIAIO/ZINC. BIANCA ISO4161
1	60/ 3	I502027001	CASSA IN LEGNO 80x120 A RENDERE VALMEX 27 PEZZI

Figure 4.3: Bill of Material of Riello 20 kW

The BOM enumerates all the components of the heat exchanger, totaling 42 distinct parts.

To facilitate classification, the components of the heat exchanger have been represented in three different colors in the BOM:

- In green are the components manufactured internally such as tube, coil etc.
- In white are represented components such as silicone, spacers, inserts etc.

- In blue are listed the components of the burner are represented.
- In yellow are represented the components of screws and bolts.

Once the BOM and the layout of VS 1.0 were thoroughly reviewed, it became possible to design the Spaghetti Chart for the production of the Riello 20 kW heat exchanger. The BOM, which provides both the names and codes of each component, played a crucial role in this process, offering clear identification of all parts involved.

The Spaghetti Chart visually represents the movement of all components listed in the BOM, ensuring a complete and accurate mapping of the material flow in VS 1.0. In this diagram, **continuous lines** were used to trace the forward paths indicating the flow of materials and semi-finished products as they progress through various stages of production. However, **dashed lines** were employed to depict the return paths, which show the reverse movements or backtracking that occur throughout the process. Each line in the chart was carefully labeled with the corresponding component code from the BOM, ensuring that every movement was clearly linked to a specific part of the heat exchanger.
The Spaghetti Chart of Riello 20 kW in VS 1.0 is presented in the image that follows (4.4):

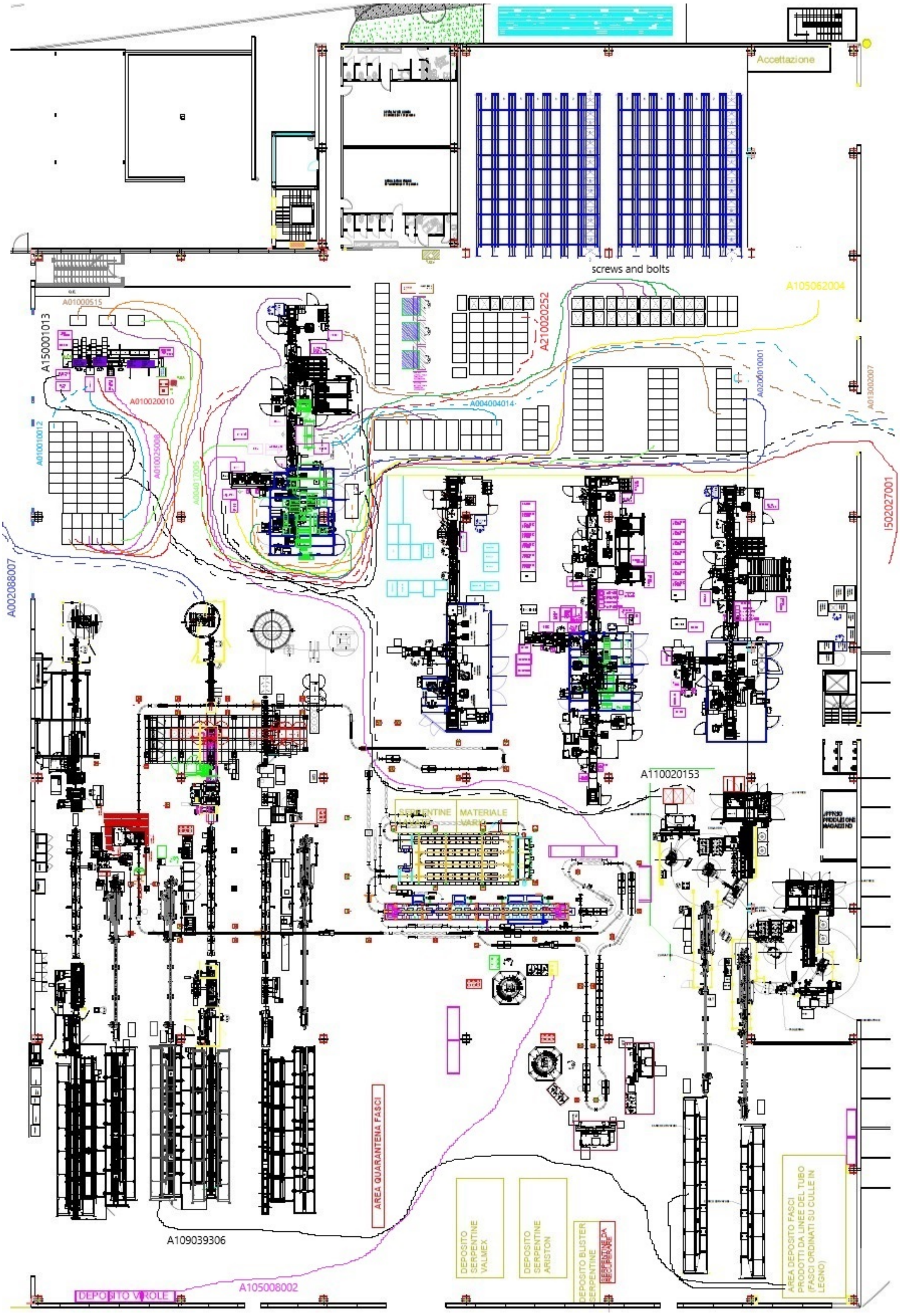


Figure 4.4: Spaghetti Chart of Riello 20 kW

This detailed mapping provided an invaluable tool for analyzing the efficiency of the internal logistics flows. By visualizing the precise routes taken by materials, it was possible to identify areas where excessive movement or unnecessary handling occurred, revealing key opportunities for process optimization. The Spaghetti Chart, therefore, not only facilitated the understanding of material flow but also highlighted potential inefficiencies that could be addressed through the application of Lean Manufacturing principles, the topic I will cover in chapter [5] of this article.

4.2 Value Stream Mapping: a pathway to continuous improvement

Value Stream Mapping (VSM) is a fundamental tool in Lean Manufacturing, used to analyze and optimize production processes by mapping every step of the product's value stream [2.1.2].
In the context of producing the Riello 20 kW heat exchanger within Value Stream 1.0 (VS 1.0), VSM played a crucial role in mapping the entire production flow, from raw materials to the finished product.

By systematically mapping the flow of materials and information in the context of production of Riello 20 kW heat exchanger, VSM allows for a comprehensive analysis of the production process. This analysis helps to pinpoint inefficiencies such as bottlenecks, excessive lead times, and wasteful practices. The benefits of applying VSM in this context include improved transparency in the production process, better communication among team members, and the ability to make informed decisions based on real data.

The operation of VSM involves the following key steps:

1. **Define the scope and choose the product family:** in this initial step, it is crucial to clearly define the scope of the mapping process. The first task is to choose the product family, which refers to a group of products that share similar processes or components. In this case, the product family refers specifically to the Riello 20 kW heat exchanger and any variations or models of heat exchangers that share similar components and production processes within the VS 1.0.

2. **Gather Information:** collect data about the current process, which may include production times, inventory levels, lead times, and resource allocations. Engage with team members who are directly involved in the process to gain insights into their experiences and challenges. This information will be critical in creating an accurate representation of the current state.

3. **Create the Current State Map:** begin mapping the existing process using symbols to represent different elements such as processes, materials, and information flows. The current state map visually depicts all activities involved in the production of the Riello 20 kW, including both value-adding and non-value-adding steps. This step provides a clear overview of the workflow and highlights areas of waste and inefficiency.

4. **Analyze the Current State:** once the current state map is complete, analyze it to identify bottlenecks, delays, and other inefficiencies. Look for activities that do not add value to the product or process, such as excess handling, waiting

times, or redundant steps. This analysis is a crucial passage that provides a foundation for developing improvements.

5. **Develop the Future State Map:** collaboratively design a future state map that outlines an optimized version of the process. This future state should minimize waste and streamline operations, resulting in shorter lead times and reduced costs. Use the insights gained from the current state analysis to propose specific changes to processes, inventory levels, and workflows.

By implementing the changes identified in the Future State Map, the production of the Riello 20 kW heat exchanger can become more streamlined, ultimately leading to reduced lead times, lower costs, and enhanced product quality.

4.2.1 Key Elements and Symbols of a Value Stream Map

The VSM is divided into three main areas, as you can see from the image (4.5), that provide a complete view of the flows of materials and information within the production system.

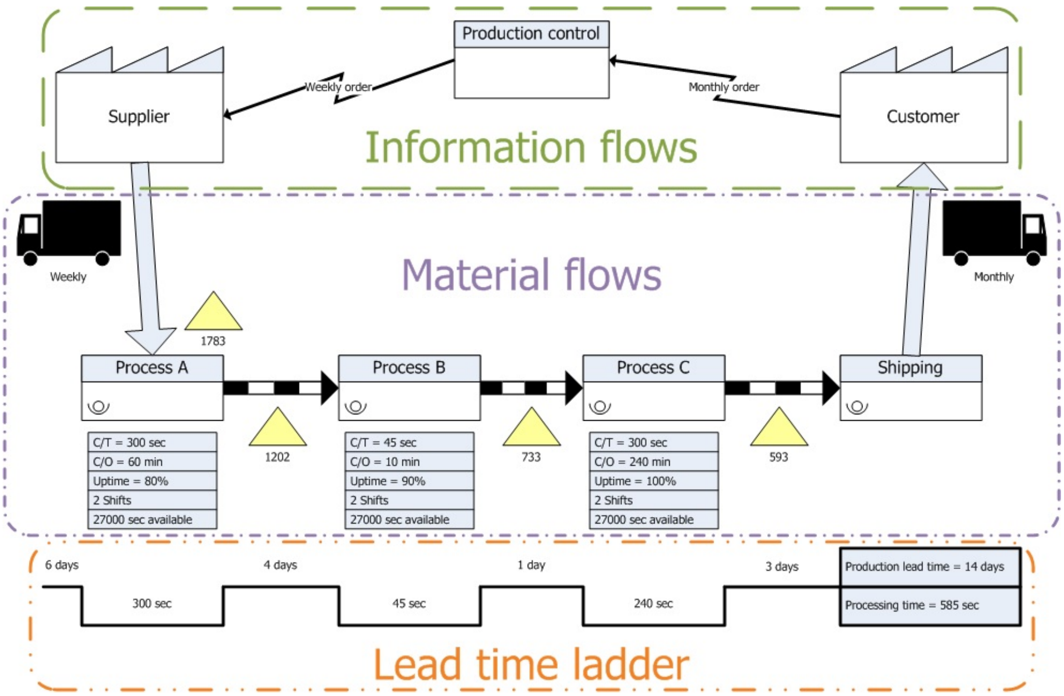


Figure 4.5: Three different areas of Value Stream Mapping

Then an explanation of these three fundamentals areas:

Information flow

The Information Flow located at the top in a VSM (4.5) represents how data and communication travel through the production process, ensuring that orders are

managed effectively and that production aligns with customer demands. This flow details interactions between different departments, suppliers, and customers, which are essential for coordinating production schedules and inventory management.
The Information Flow allows organizations to:

1. Track customer orders;
2. Communicate production requirements;
3. Monitor inventory levels;
4. Optimize production schedules.

Some common symbols used to represent elements of the Information Flow in a VSM are shown in the image (4.6), and are:

- **Customer/Supplier:** represents the start or end of the value stream, indicating where the demand comes from or where the product is sent.
- **Manual Information:** a straight arrow pointing to the right, showing that information is passed manually.
- **Electronic Information:** a lightning-shaped arrow, indicating that information is sent electronically, such as through emails or software systems.
- **Production Control:** denotes the system or person responsible for overseeing and managing the production schedule.
- **Kanban Post:** represents a location where kanban cards are collected and organized, often used for visual control of production flow.
- **Production Kanban:** a tag that signals the need to produce more items.
- **Withdrawal Kanban:** a card used to indicate that parts should be withdrawn from a specific location to feed the production process.
- **Shipment Arrow:** indicates the flow of products or information in reverse, used for tracking orders, shipments, or communication going backward in the flow.

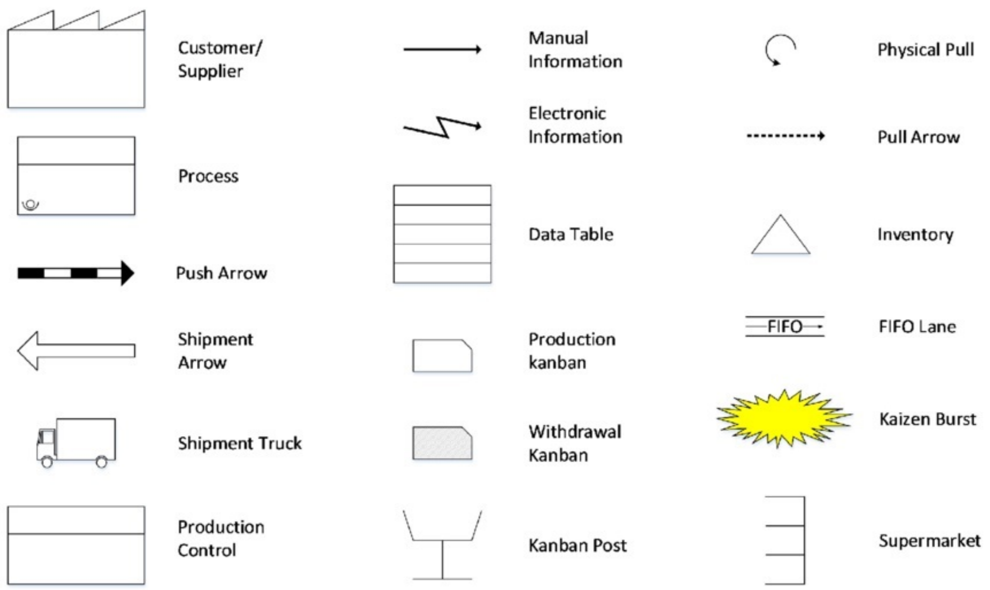


Figure 4.6: Symbols used in Value Stream Mapping

These symbols are essential in representing the flow of information and materials in a VSM, making it easier to identify bottlenecks, inefficiencies, and opportunities for improvement in a production system.

Material flow

The material flow area, found in the middle section of the map (4.5), focuses on the movement of physical products through the production system. It traces the flow of materials from suppliers, through various processes, and finally to customers.
The key are even included in image (4.6) symbols used here include:

- **Push Arrow:** a dark arrow showing that production is based on forecasts or predetermined schedules, pushing materials forward regardless of demand.
- **Pull Arrow:** a dashed arrow indicating a pull-based system where the production is triggered based on actual demand, such as through a Kanban system.
- **Physical Pull:** represents the physical movement of products or materials when pulled based on demand.
- **Process Box:** represents a specific operation or activity in the value stream where work is done. It is often used to show steps in the production process. in the process box is specified the number of operators working on that line and if the line is U-shaped.
- **Data Table:** a simple table that summarizes the data related to processes, like cycle time or lead time. In the data table of VSM are listed the following

parameters used in industrial production: **Cycle Time (CT)** the time it takes to complete one unit of production from start to finish helpful to compare this with the Takt Time (4.2), **Changeover Time (CO)** the time required to switch from producing one product to another, **Overall Equipment Effectiveness (OEE)** that evaluates the performance of machinery or production lines and, **Production time (PT)** the total time spent on production activities during a given period.

- **Shipment Truck:** a truck symbol indicating the physical transportation of goods between locations, such as between suppliers and production facilities.
- **Inventory:** a triangle symbol that indicates the storage of materials at various stages of the process.
- **FIFO Lane:** a lane that ensures the "First In, First Out" movement of products, making sure that older stock is used before newer stock. The logic behind FIFO Lane is quite simple: the first part that goes in the inventory is also the first part that goes out. There is a limit to the maximum number of parts in a FIFO lane. A full FIFO eventually stops the preceding process, whereas an empty FIFO naturally stops the succeeding process [24].
- **Kaizen Burst:** a starburst shape that highlights areas in the value stream where specific improvements or changes are needed.
- **Supermarket:** a controlled inventory location where materials are stored and pulled as needed by downstream processes.

The material flow area allows the identification of bottlenecks, inefficiencies, and inventory issues, showing where materials accumulate or experience delays.

Lead Time Ladder

The Lead Time Ladder shown at the bottom of the Value Stream Map (4.5) represents the total time required to produce a product, broken down into different stages of production and processing times.
The ladder is divided into two key parts, one above and one below the timeline:

- **Above the Timeline – Total Lead Time (TLT):** this part represents the waiting time between the various production stages. It is measured in **days** and this includes all the time from the start to the end of the process, including both value-adding and non-value-adding activities such as waiting or delays [2.3.1].
- **Below the Timeline – Value-Added Time (VAT):** this part represents the actual processing time that directly contribute to transforming the product or service in a way that the customer values. It is measured in **seconds**

and reflects the time it takes to perform the tasks necessary to transform the material into a finished product.

The ratio between lead time and processing time helps in evaluating the efficiency of the production system as shown by the equation (4.1).

$$VAR = \frac{Value\,Added\,Time}{Total\,Lead\,Time} \times 100 \tag{4.1}$$

Ideally, the goal is to maximize processing time, which adds value to the product, while minimizing Lead Time, which represents non-value-adding activities such as waiting or transportation.
A high Lead Time to process time ratio indicates inefficiencies in the production flow, where materials spend too much time in idle states rather than being processed. This suggests that the production system may suffer from delays, bottlenecks, or unnecessary steps.
Conversely, a low ratio reflects a more efficient production process, where materials move quickly through the value-adding stages with minimal waiting time. In such cases, the overall workflow is streamlined, allowing for faster production cycles and improved operational performance.

By analyzing this ratio, companies can identify areas where waiting times can be reduced, bottlenecks can be eliminated, and material flow can be optimized. This leads to shorter production lead times and ultimately increases productivity and overall efficiency in the manufacturing process.

4.2.2 Implementation of Value Stream Mapping in the production of the Riello 20 kW within VS 1.0

In a significant step towards enhancing operational efficiency, the company has decided to undertake a Value Stream Mapping activity for the first time.
This initiative reflects a commitment to lean manufacturing principles and continuous improvement within the organization. To initiate this process, one of the most critical components, the Riello 20 kW heat exchanger, was selected for analysis.

The choice of the Riello 20 kW was not arbitrary; it is a key product that plays a central role in the company. By focusing on this component, the VSM activity aims to uncover inefficiencies and areas for improvement in its production flow.

As outlined at the beginning of this paragraph [4.2], the implementation of a Value Stream Mapping (VSM) involves several essential steps.

The first step in the realization VSM of Riello 20 kW is calculating the **Takt Time**, a crucial metric in Lean Manufacturing that determines the available time to produce a product in order to meet customer demand. Derived from the German word "Takt," which means rhythm or cadence, Takt Time represents the pace at which products

must be completed to satisfy customer requirements.
To calculate Takt Time, the following formula is used:

$$Takt\,Time = \frac{Available\,Production\,Time}{Customer\,Demand} \tag{4.2}$$

In the previous equation (4.2) **Available Production Time** refers to the total time available for production during a specific period (e.g., hours per day), excluding breaks, maintenance, and other non-productive times, whereas **Customer Demand** indicates the number of units required by customers within the same time frame.
Takt Time is important for several reasons:

1. **Production Balancing:** it aligns production flow with customer demand, preventing both overproduction and underproduction.

2. **Bottleneck Identification:** it helps pinpoint production bottlenecks, enabling timely corrective actions.

3. **Resource Allocation:** Takt Time ensures efficient use of labor and machines to meet production targets effectively.

4. **Continuous Improvement:** regular monitoring of Takt Time encourages teams to seek ways to reduce cycle times and improve efficiency.

The Takt Time, calculated for the production of 1.782 units of Riello 20 kW over a period of 3 weeks with the production distributed over three shifts of 7,5 hours each is approximately **682 seconds** per unit.
Orders from the client company, Riello, are received weekly with a forecast period of seven days. Once these orders arrive at the Production Control department, they initiate the orders for raw materials from the suppliers.

As observed from the BOM (4.3), the Riello 20 kW heat exchanger is composed of 42 different components. This number is too high to effectively display all parts within a single VSM. Therefore, I have decided to represent the five most critical components in the VSM.
The components and how they are supplied are listed below:

- Coil Tape - code A002088007

- Coil Casing - code A105008002

- Frontal Cover - code A004004014

- Back Casing - code A004017005

- Burner - code A150001013

In the VSM created for the production of the Riello 20 kW heat exchanger, each of the critical components has a dedicated branch to represent its flow within the manufacturing process. Now, it will proceed to examine each of these components and how they are integrated into the VSM.

Coil Tape - code A002088007

The supply and processing of the coil in the production of the Riello 20 kW heat exchanger follow a structured system.
Every week, the Production Control department sends procurement orders with a 7-day forecast. The minimum order quantity for the coils is 28.000 kg, delivered by truck to the warehouse besides the VS 1.0 within the industry, once a week.

This warehouse adjacent to the VS 1.0, and more generally, the company's Main Warehouse operates under a **Consignment Stock System (CS)**, where the supplier retains ownership of the stock until it is used in production.
This technique is a novel approach to the management of inventories in supply chains, considering that is based on an improved collaboration between the company and its suppliers [25].
Briefly, under a CS policy, the relationship between a company and a supplier is based on the following simple rules:

1. The supplier will guarantee the company the continuity of an available stock between a minimum level s and a maximum level S: the stock will be stored in the company's raw material depots, close to the production lines [25].

2. The company may draw on raw materials daily, according to its needs. The supplier is paid for these materials according to their agreement, hypothetically up to a daily frequency, so that the information concerning the consumption trend is also constantly refreshed and immediately transferred to the supplier [25].

In such a way, the continuous replenishment from the supplier protects the company against demand fluctuations and costs determined by eventual stock out may also be debited to the supplier, by means of contract penalties. On the other hand, the supplier has a better perception of his customer's requirements [25].

When the coil tape is needed, the Tube Line 2 [3.4.1] operates under a Pull system [2.5.2], calling for the material from magazine adjacent VS 1.0. The coils are then transferred to the Tube Line 2, where they are processed according to the cycle described in paragraph [3.4.1]. On average, the coils remain in storage in this warehouse for 3 days, with a typical inventory level of 110.000 kg. This system ensures the continuous availability of materials while maintaining a balance between supply and demand.
Once the coil tape reaches Tube Line 2, it undergoes processing with a cycle time of 31

seconds to be processed by tube. The operation is performed by 1 operator. Following a Push system [2.5.1], the processed tubes are then transferred to Automatic Island 5 [3.4.2]. Between these stages, the material waits for 1,5 days on average, with an inventory of around 1.000 pieces.
At Automatic Island 5, the tube is further processed with a cycle time of 63 seconds to be processed by coil. The operation is performed by 1 operator. After processing, the material is again moved with Push Logic to CTF4, where it waits for an average of 12 hours between transfers, with an inventory of approximately 240 pieces.
At CTF4 [3.4.3], the coil is assembled with other components mentioned in BOM [4.1.1], completing the production with a cycle time of 54 seconds. The CTF4 is a U-shaped station where the point of material input coincides with the point at which the operator takes the finished product and places it in the packaging. The operations are performed by 4 operators. Once the finished product is ready, it is packed and transferred to the warehouse in a FIFO mode for shipment, where it remains for around 2 days, with an average inventory of 2.400 units.
Shipments to the client, Riello, occur twice a week, with each consignment consisting of 1.782 pieces equally to the customer's commission, ensuring a continuous supply of finished products while managing inventory effectively.

Coil Casing - code A105008002

Analyzing the Coil casing branch of the VSM provides insight into the flow and handling of this crucial component within the production process.
The Coil casing, along with the Burner, is one of the key components produced internally, and specifically is manufactured in the Stamping department [3.2.1]. The process begins when the production control department sends weekly procurement orders to the stamping department, with a forecast covering the next 7 days. A minimum batch of 420 Coil casings is delivered once a week, following a provisioning Push system [2.5.1]. Upon arrival in the VS 1.0 area, the Coil casings are stored on dedicated shelves, where they remain for an average of 10 days, with an inventory level of around 4.200 units.
Before the Coil casings are requested with a Pull system [2.5.2] from CTF4 assembly line [3.4.3], they must be washed at the central washing station, a process that takes approximately 60 minutes. Once washed, they are placed on the washed Coil casing shelves, where they are stored for about 12 hours, with an average inventory of 600 units. After this, the Coil casings are transferred to the CTF4 line for final assembly as part of the complete product.

Frontal Cover - code A004004014 and Back Casing - code A004017005

The VSM branches for the Frontal Cover and Back Casing follow a very similar pattern. For both components, the production control department issues weekly orders based on a 7-day forecast, with deliveries arriving once a week. The minimum

order quantity for the Frontal Cover is 1.610 pieces, while the minimum order quantity for the Back Casing is 144 pieces. Once the orders arrive, they are stored in the Main Warehouse under a consignment stock arrangement.
When the production line requires these components, they are pulled from the Central Warehouse and transferred to the VS 1.0 warehouse according to a Pull system [2.5.2]. In the VS 1.0 warehouse, they typically remain for approximately 3 days before being used in the production process in CTF4. The average inventory level for the Frontal Cover in the warehouse is 14.000 pieces, while the average inventory level for the Back Casing is 3.600 pieces.

Burner - code A150001013

The VSM branch dedicated to the Burner requires separate consideration since it is the second completely internally produced component analyzed. However, unlike the Coil casing, which is a single part, the Burner is an assembled product made up of nine different components, as you can see from the following image (4.7).

9	A010025008	ISOLANTE PORTA VALMEX - 1EL SAPCO / *BURNER DOOR STONE*	1	
8	A010015014	GUARNIZIONE PERIMETRALE PORTA VX / *PERIMETER GASKET*	1	
7	A040002010	VITE ELETTRODO / *ELECTRODE SCREW*	2	Coppia di serraggio / *Tightening torque*: 2,3 ± 0,15 Nm
6	A010020010	ELETTRODO DI ACCENSIONE SAPCO KANTHAL APM E00402 / *IGNITION ELECTRODE*	1	
5	A010015017	GUARNIZIONE ELETTRODO SAPCO / *ELECTRODE GASKET*	1	
4	A040002019	VITE TORX TRIL T BOMB M5X10 T25 ISO 10664 UNI EN ISO 4042 / *BURNER SCREW*	4	Coppia di serraggio / *Tightening torque*: 3,5 ± 0,2 Nm
3	A010005015	BRUCIATORE PREMIX - PRX0648 - BECKETT / *BURNER*	1	
2	A010015021	GUARNIZIONE BRUCIATORE PORTA VX / *BURNER GASKET*	1	
1	A010010012	PORTA BRUCIATORE 1EL SAPCO - VX / *BURNER DOOR*	1	
POS	CODICE / *PART NUMBER*	DESCRIZIONE / *DESCRIPTION*	Q.TÁ / *Q.TY*	NOTE / *NOTES*

Figure 4.7: Bill of Materials of Burner

This distinction emphasizes the complexity of the Burner manufacturing process, which involves multiple sub-components (represented in image 4.8) that must be integrated before the Burner can be finalized. As such, this portion of the VSM will focus on both the production and assembly stages of the Burner's various parts.

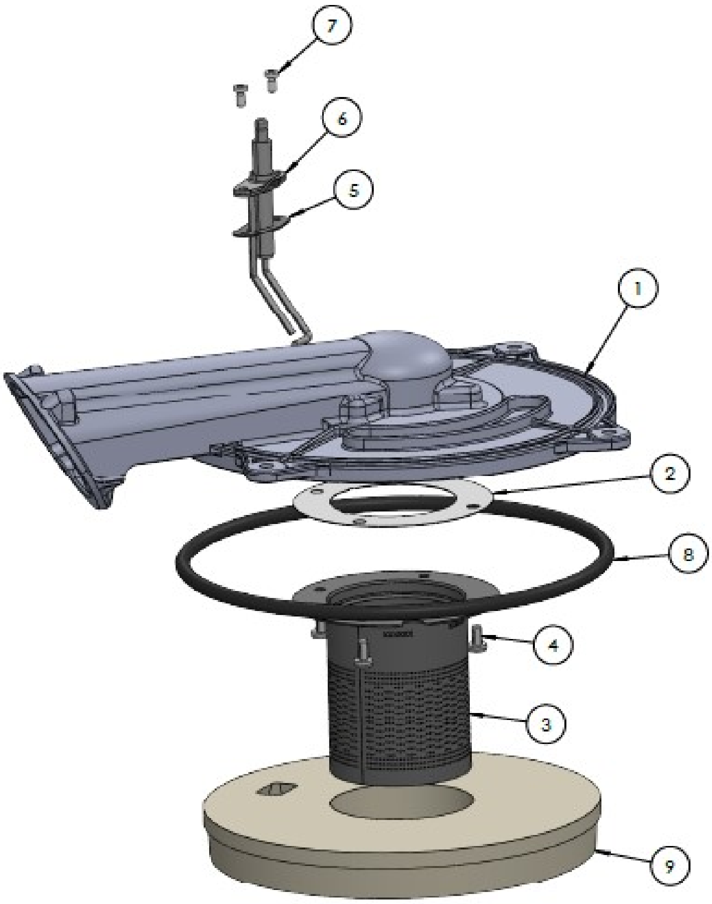


Figure 4.8: Exploded figure of Burner

The Burner is a core component within the heat exchanger, playing a key role in the overall functionality of the system. Its primary purpose is to generate the thermal energy necessary for heating the fluid that circulates through the heat exchanger. This process is essential for achieving the desired temperatures needed for efficient operation. In addition to heat generation, the Burner ensures precise control over the combustion process.

The design of the Burner allows for effective heat transfer to the fluid, ensuring that the heat produced is efficiently transmitted to water circulating within the coil casing. This efficient transfer is fundamental for the overall effectiveness of the system, as it directly influences the performance of heat exchanger.
As part of the heat exchanger assembly, the Burner is integrated with various other components, contributing to the cohesive operation of the entire system.

Similar to the approach taken with the heat exchanger, I have also developed a VSM for the Burner to achieve similar objectives.
In the case of the Burner, we have focused on four key components that are essential

for its assembly and have been included in BOM (4.7).
The main components represented in VSM are:

- Burner Door - code A010010012
- Premix Burner - code A010005015
- Electrode - code A010020010
- Insulating Disc - code A010025008

To graphically represent the VSM, we accounted for the production flow of the Burner and its key components. The production orders for the Burner amount to 3.600 pieces over the course of three working days. Based on this, the Takt Time calculated with the formula (4.2) is **49 seconds**.
Moreover, the production scheduling for the Burner assembly at the CTF4 station is organized through weekly orders, with a 28-day forecast.

Below, we detail the VSM branches for all the key components of the Burner. Each branch represents the flow and processes associated with individual components, showing how they are procured, assembled, and integrated into the final Burner assembly.

- **Burner Door - code A010010012 and Premix Burner - code A010005015**

  To graphically represent the VSM, we considered the fact that the Burner Door and the Premix Burner follow a similar production cycle. Both components are supplied using the same procurement process and are assembled at the same U-shaped station, allowing them to share the same flow within the value stream.
  Both components are ordered weekly by the Production Control, accompanied by a 7-day production forecast. The minimum order quantity for the Burner Door is 228 pieces, while the minimum order for the Premix Burner is 1.200 pieces. These components are shipped once a week and stored in the Main Warehouse under a consignment stock system.
  To complete the Burner door supply process, before being brought to the Burner assembly line, the door must first be washed in the aluminum department's washing station [3.2.2]. This operation takes 20 minutes and is handled by a single operator. The washing system operates on a Push system [2.5.1]. The average stock quantity held before being sent to the Burner assembly is 228 pieces.
  When a production order from CTF4 is issued, the materials are moved to the VS 1.0 warehouse following a Pull logic system [2.5.2]. The Burner Door remains in storage for two days before being used, with an average stock of 11.000 pieces. Similarly, the Premix Burner stays in storage for two days with

an average stock of 10.000 pieces.
Once both components are needed for assembly, they are moved to the vicinity of Workstation 1 of the Burner assembly area, where a single operator works with a cycle time of 34 seconds. After completing assembly at Workstation 1, the semi-assembled Burner is transferred to Workstation 2 for final assembly. This movement follows a **Sequenced Pull Logic**: this represents pulling of material by a downstream process from upstream process, in such a way that there will not be more than a defined inventory in between them and ensures that parts are moved precisely when needed for the next step in the production process, preventing overproduction and reducing lead time. The transfer time between the two stations is 21 seconds, ensuring smooth and efficient production flow.

- **Electrode - code A010020010 and Insulating Disc - code A010025008**

  Similarly, the Electrode and the Insulating Disk insulation exhibit a nearly identical flow, as they are both procured and assembled through similar steps. Production Control issues weekly replenishment orders for the Electrode, with a 50-day forecast. For the Insulating Disc, orders are also issued weekly, but with a shorter 7-day forecast, and this item is managed as consignment stock in the Main Warehouse. The delivery frequency for both items is once a week, with a minimum order quantity of 4.000 pieces for the Electrode and 600 pieces for the Burner door insulator.
  Before being required by the Burner assembly line, the Insulating Disc remains in the VS 1.0 warehouse for two days, while the Electrode is used immediately upon delivery. Both components are assembled at Workstation 2 of the Burner assembly line, where a single operator handles the process with a cycle time of 32 seconds.
  Once assembly is completed at Workstation 2, the product undergoes testing. Afterward, it is transported along the assembly line on a conveyor, completing the loop in 335 seconds. This movement follows the Sequenced Pull system, which ensures that each part is delivered exactly when needed for the next production step, minimizing excess inventory and reducing waiting times. After the conveyor loop, the product returns to Workstation 1, where the operator places it in the blister of the finished product in a FIFO mode. Once the Burner assembly is completed, it is stored in the VS 1.0 warehouse for an average of two days, with an average inventory of 720 pieces.

Having explained the branches of the VSM for the Burner components, it's important to introduce the visual representation of the Burner assembly in this thesis.
The VSM for the Burner (4.9) outlines the journey of its key elements—such as the Burner door, premix Burner, Electrode, and insulating door—through the production line.

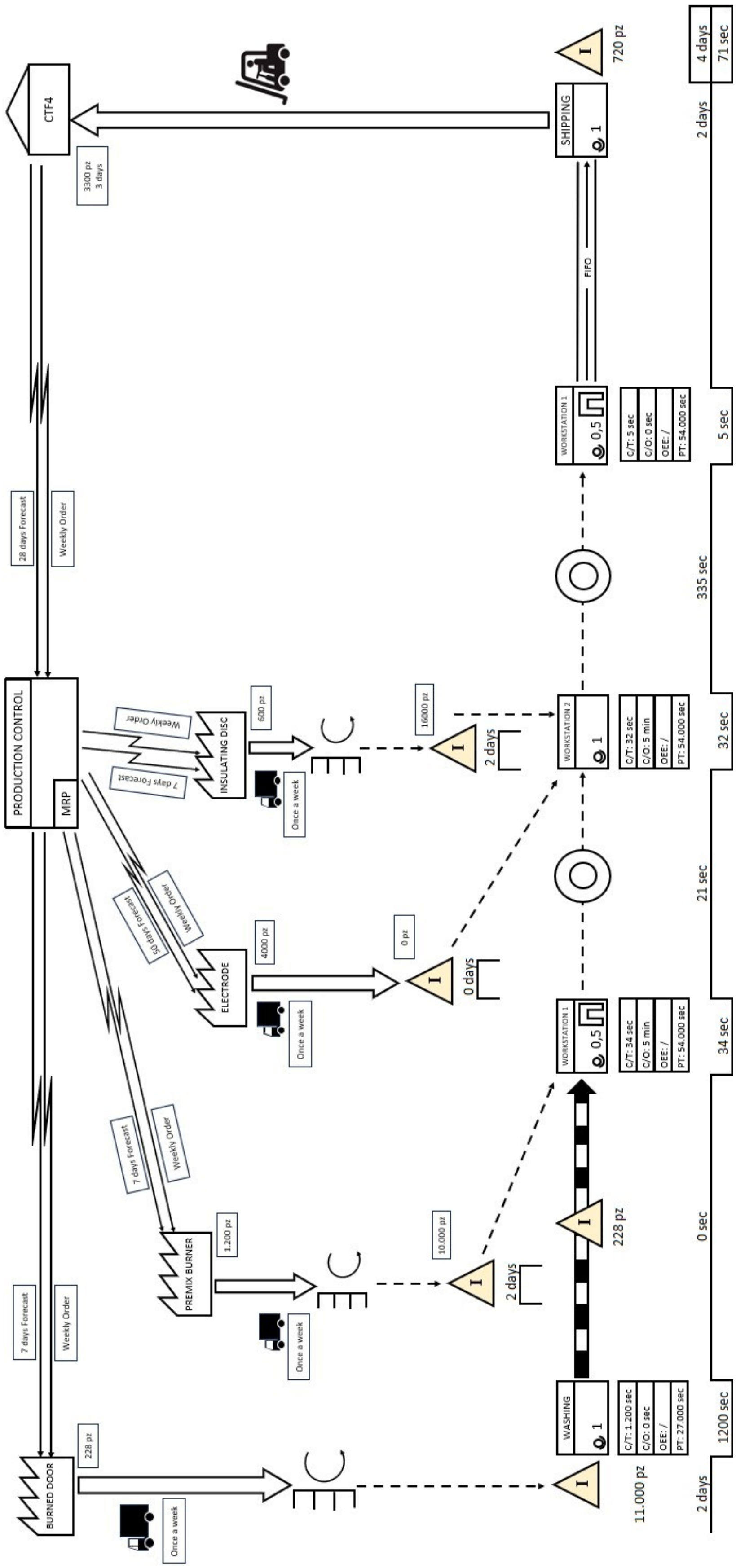


Figure 4.9: Value Stream Map for Burner

This VSM diagram (4.9) provides a clear and structured view of the material and information flow, showing where each component is sourced, stored, processed, and assembled. By analyzing the VSM, it becomes possible to pinpoint inefficiencies, delays, or excess inventory and propose lean improvements, of which I will talk in the next chapter [5].
To calculate the VAR for the Burner in VSM we used the equation (4.1). In this case, the VAR is measured at **71 seconds** (the 1.200 seconds needed to wash are not taken into account because they are not considered as value added time), representing the time spent on activities that directly add value to the product. The TLT, on the other hand, is **4 working days** and therefore a total of **345.600 seconds**, and the ratio gives a VAR value of **0,0205%**.

Now that I have detailed the various branches of the VSM for the complete heat exchanger, it is important to present the visual depiction of the entire process in this thesis, as is shown in the following image (4.10).

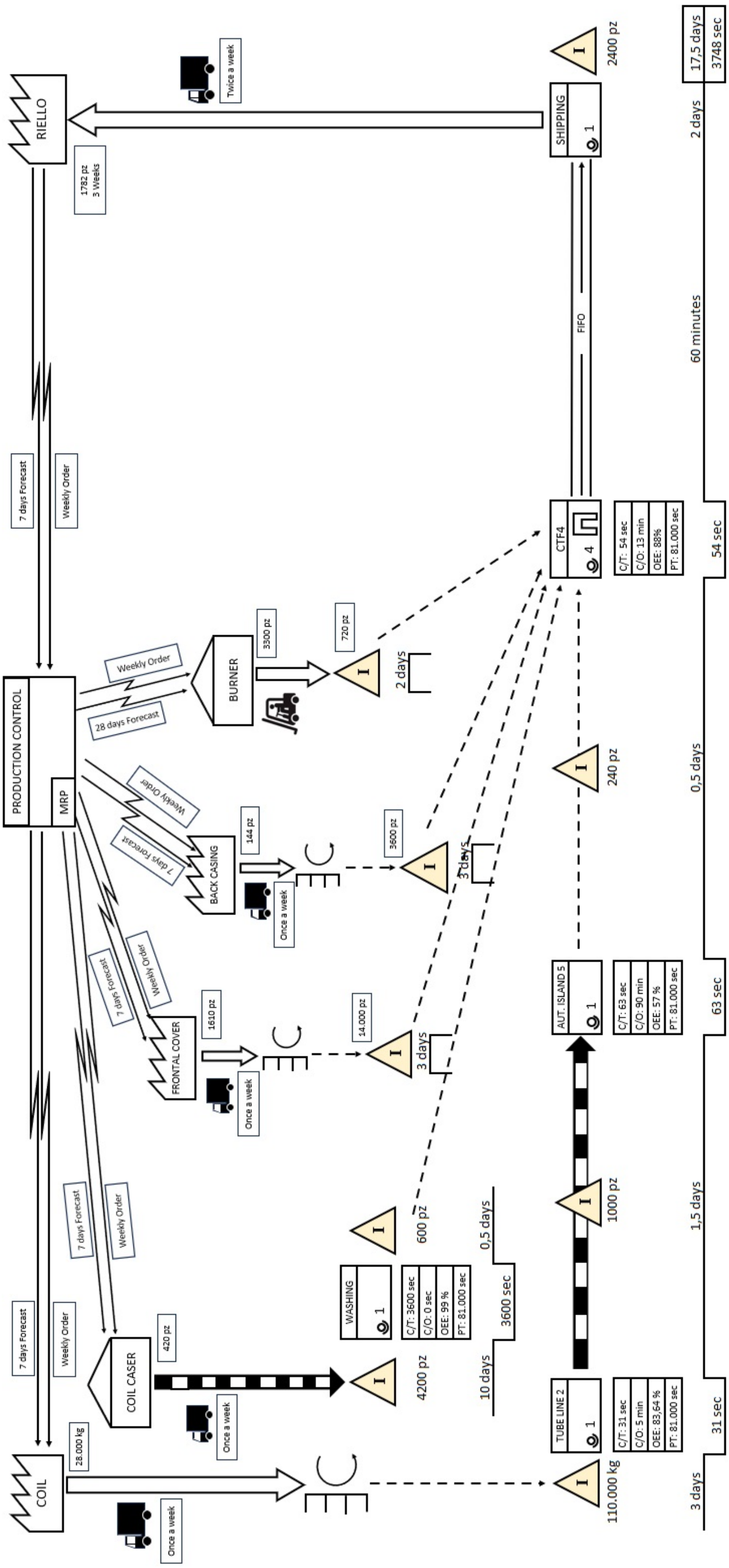


Figure 4.10: Value Stream Map for Riello 20 kW heat exchanger

As repeatedly stated above, this VSM (4.10) illustrates the complete flow of materials and information throughout the manufacturing process, tracking each component's journey from procurement through to final assembly.
Again, to calculate the VAR for the heat exchanger Riello 20 kW in the VSM of the Riello 20 kW, we compared the VAT of **3.748 seconds** to the TLT of **1.512.000 seconds**, which accounts for **17,5 working days**, which corresponds a value of VAR of **0,248%**.
Through this analysis, we aim to streamline the process, minimize delays, and optimize resource use, ultimately enhancing the production flow, all aspects of which I will explain in the next chapter [5].

Chapter 5

Analysis of Results and Lean Improvement Proposals to Enhancing Efficiency in VS 1.0

In the final chapter of my thesis, I will present the results derived from the application of lean tools to Value Stream 1.0, highlighting the direct impact of these methodologies on waste reduction, production flow optimization, and overall efficiency improvements. Having examined and analyzed the Value Stream using key Lean instruments such as the Value Stream Mapping (VSM), Spaghetti Chart, and Kaizen, this chapter will delve into the outcomes of that analysis.
Specifically, it will highlight the inefficiencies identified, the improvements that have been made, and the further potential enhancements proposed to streamline production flow, reduce waste, and optimize resource utilization. The chapter aims to provide actionable insights that not only address current challenges but also set the foundation for long-term operational excellence within VS 1.0.

5.1 Insights from the Spaghetti Chart: analysis and opportunities for improvement

From the analysis of the Spaghetti Chart (4.4), as detailed in the previous chapter [4.1.1], several inefficiencies have been identified in the current flow of materials within VS 1.0.
These observations highlight critical areas where improvements can be implemented to streamline operations and reduce waste:

1. **Lack of designated areas for incoming materials and marked spaces for consumed materials:** the current setup does not provide clearly defined spaces for incoming materials. This absence of designated areas results in confusion, improper storage, and the inefficient use of space. Additionally, there are no clear markers for where consumed materials should be placed, leading to disorganization and potential delays in processing.

2. **Congestion points along movement paths:** several areas within the production environment experience bottlenecks, where operators and materials frequently converge, causing delays and unnecessary waiting times. This congestion negatively impacts the smooth flow of work and increases the likelihood of accidents or errors in material handling.

3. **Absence of specific zones for empty pallets:** empty pallets are often placed haphazardly throughout the facility due to the lack of designated areas for their storage. This not only clutters the workspace but also poses a risk to safety and further exacerbates congestion.

4. **Presence of unnecessary materials on the shop floor:** the workspace is cluttered with materials that are not directly useful for the production lines, contributing to confusion and inefficiency. This disorganization leads to time wasted in locating necessary items and managing space constraints.

5. **Shared pathways between operators and forklifts:** another significant issue identified is the shared use of corridors by both operators on foot and forklift drivers. This situation presents a safety hazard and slows down the overall material movement, as operators must constantly navigate around the heavy equipment.

After identifying the critical issues in the current material flow within VS 1.0, as discussed earlier, a series of targeted improvement proposals have been formulated. These proposals aim to address the congestion, lack of organization, and safety risks present in the system, ultimately optimizing the workflow and enhancing overall efficiency:

1. **Decongest high-traffic areas:** one of the key issues identified was the presence of congestion points along material movement paths. To address

this, it is necessary to decongest these high-traffic zones, allowing for smoother movement and reducing delays. By creating alternative routes and better spacing, the workflow can be made more efficient, and the risk of accidents or disruptions will be significantly lowered.

2. **Establish designated areas for material positioning and marker placement:** to ensure better organization in the workspace, designated areas for incoming materials must be clearly defined. By creating marked spaces for both the storage of incoming materials and the return of consumed materials, the handling process will be more efficient, and the risk of misplaced or forgotten materials will be minimized.

3. **Supply lines only with necessary materials:** a key improvement focuses on reducing the clutter and overstocking of materials that are not immediately needed by the production lines. By ensuring that only the necessary materials are supplied, space can be optimized, and time wasted in managing excess materials can be avoided. This will improve the organization and workflow, allowing operators to focus on the tasks at hand without unnecessary distractions.

4. **Separate corridors for Operators and Forklifts:** to enhance safety and reduce the risk of accidents, separate corridors should be established for operators on foot and forklift drivers. This separation will prevent congestion and minimize the risk of collisions, ensuring that both operators and heavy machinery can move freely and safely through the production area.

5. **Eliminate movement through inconvenient points:** in areas where movement is particularly difficult due to narrow or awkward spaces, it is important to eliminate unnecessary travel. By redesigning the layout and rerouting material flows to avoid these troublesome areas, the efficiency and safety of the overall system will improve.

After identifying the problems and potential improvements through the Spaghetti Chart analysis [4.1.1], a key decision was made to begin optimizing the material flow by applying Lean Principles to the **WIP (Work In Progress)** area in VS 1.0, illustrated in image (5.1), namely the area that is located in the lower right of the image of VS 1.0 (4.2).

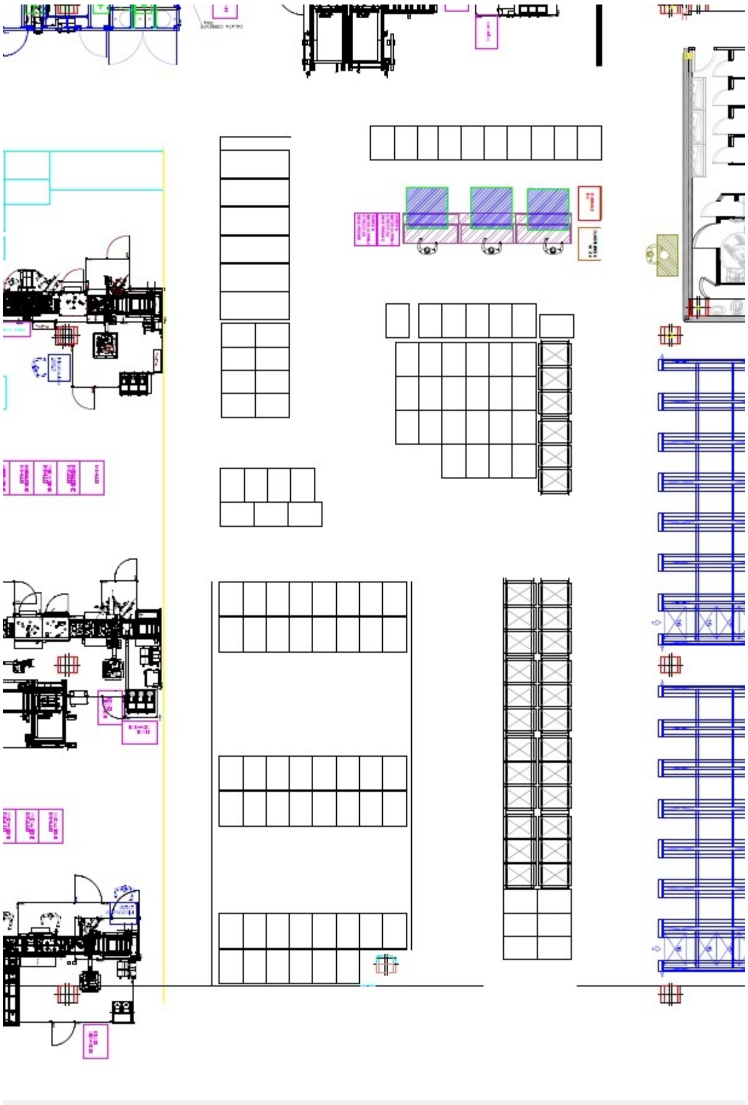


Figure 5.1: Current Layout WIP Area in VS 1.0

Work in Process (WIP), (in some cases also referred to as Work in Process), refers to inventory which has entered the manufacturing process, is no longer part of the inventory of raw materials, but is not yet a complete product [26]. In manufacturing, reduction of WIP results in a higher level of liquidity, improved cash flow, better customer service and lower risks to the business.
Having accurate forecasts will promote awareness and as a result, provide a sound basis for planning. The desired outcome should be a lessening of the buffer sizes in order to maintain continuous flow and avoid overstocking [26].

Currently, the WIP Area in VS 1.0 is disorganized, with no defined system for the placement or retrieval of materials. It was originally designed to ensure that production could continue uninterrupted for up to 2.5 days. However, over time, it has lost its structure. There is no clear criterion for how materials should be stored

or picked, leading to inefficiencies such as excess handling, longer search times, and congestion in the area.
These issues result in significant waste, including excess inventory, motion, and waiting times, all of which hinder production efficiency [2.3.1].

To deliver the efficient work across the production line it is required to have the WIP limits. Reducing WIP is a key principle in Lean Manufacturing [2], and it plays a crucial role in enhancing production efficiency and overall system performance. When WIP is not properly controlled, several issues can arise, including delays, increased costs, poor quality, and bottlenecks across the production line [26].
By reducing and setting limits on WIP, significant improvements can be made in the way work flows through the system.

1. **WIP limits help manage capacity:** become easier to align the amount of work in progress with the available capacity. When too many tasks are active at once, it overwhelms the system, leading to delays and inefficiencies.

2. **WIP limits encourage systems thinking:** it becomes easier to identify bottlenecks and inefficiencies in the production line. Too much work in progress can obscure underlying problems, making it difficult to pinpoint where issues are occurring.

3. **WIP limits introduce slack into the system:** slack in a production system refers to the extra time or resources available to handle unexpected issues. When WIP is reduced, it creates this necessary slack, allowing for more flexibility in the process.

4. **Focus on finishing work rather than starting new tasks:** when teams are constantly starting new tasks without completing the ones already in progress, it leads to inefficiency and poor quality. By limiting the amount of work in progress material, teams can focus on completing tasks before moving on to new ones, which improves overall productivity and quality.

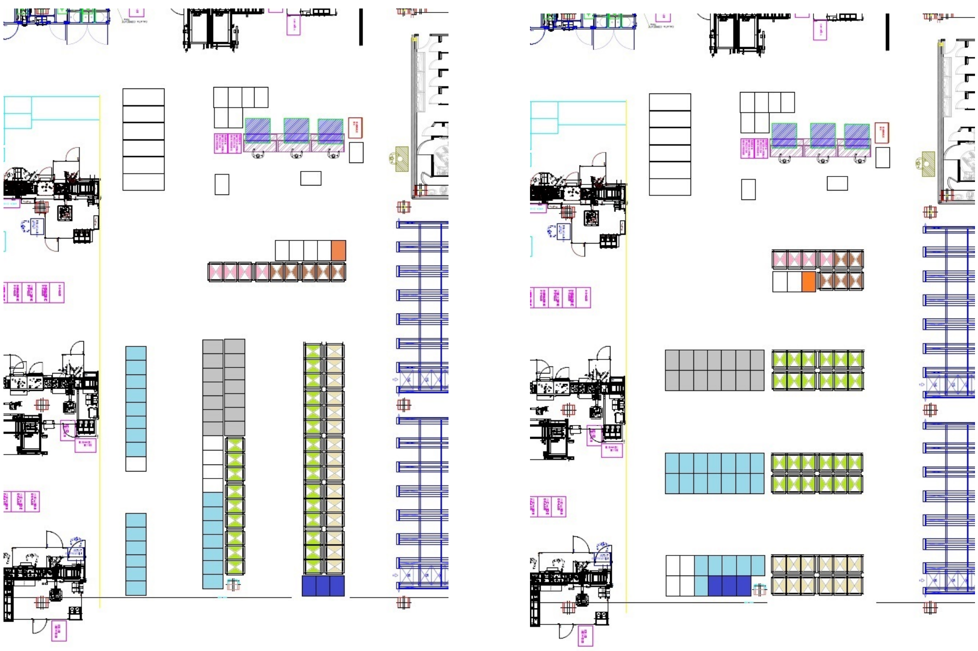
The current WIP Area, with all the associated problems, can currently accommodate **67 floor pallet spaces**, **36 pallet spaces on 3-level racks**, and **48 pallet spaces on 4-level racks**. In the WIP Area, the storage of materials is organized to maximize vertical space in order to minimize the floor space required. For example, black blister trays, which hold components like Burners (4.8), can be stacked up to three levels high. Frontal Cover [3.3.4] baskets are stackable up to two levels, while other elements, such as the Back Casing [3.3.4], which are stored on pallets, cannot be stacked at all. This approach aims to utilize the available height for storage, reducing the amount of floor space needed, though it is not always efficient due to varying stackability of the materials.

In addressing the inefficiencies observed in the WIP Area, two distinct solutions have been proposed to optimize its functionality.

- A short-term solution involves reorganizing the WIP Area based on the second of the 5S principles ("Set in Order").
- On the other hand, a the long-term solution introduces the implementation of the Mizusumashi Train system operating under the milk run cycle, as I shall explain in the following paragraphs.

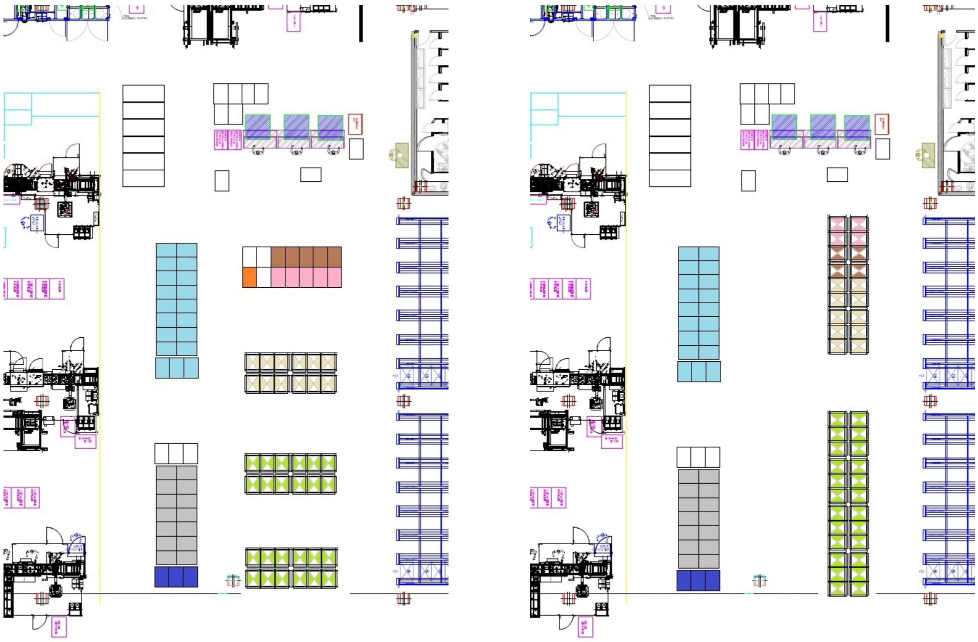
5.1.1 Optimizing the WIP Area using the 5S approach

After completing the Spaghetti Chart and analyzing the current state of the WIP area, an initial short-term solution was considered to address the identified problems. This solution involves a redesign of the WIP layout, which currently does not allow for optimal movement of operators. A significant issue stems from the lack of discipline in material placement. The warehouse worker, responsible for restocking materials, places them in the first available slot without a systematic approach.
With the four proposed layout alternatives, the aim is not only to completely re-imagine the layout of the WIP Area but also to implement the second principle of the 5S methodology **"Set in Order"** [2.4.2]. This principle focuses on organizing the workspace so that materials are assigned specific locations. In this case, similar materials would be placed together, making it much easier for warehouse workers and operators to quickly locate what they need when they need it.
The 4 different solutions are represented in the following images:



(a) First solution of the new WIP Area (b) Second solution of the new WIP Area

Figure 5.2: First and second visualization of new WIP Area



(a) Third solution of the new WIP Area (b) Fourth solution of the new WIP Area

Figure 5.3: Third and fourth visualization of new WIP Area

As can be seen from the images of the redesigned WIP Area, both the floor pallet positions and the shelving units have been organized by color coding to group similar products together.
The application of "Set in Order" in WIP Area brings several key advantages:

1. Enhances the overall efficiency of material handling, by positioning similar items in close proximity operators and warehouse staff can quickly locate the materials they need.

2. Improves inventory management, having dedicated areas for specific types of materials becomes easier to track and monitor stock levels, reducing the risk of misplaced or overlooked items.

3. It aids in maintaining a clean and orderly work environment, further supporting the 5S methodology, particularly the "Set in Order" principle.

4. Improves ergonomics for operators, with materials stored logically and in closer proximity, it reduces the need for excessive movement or lifting, minimizing the risk of fatigue or injury.

5.1.2 Implementing the Mizusumashi Train System with the Milk Run Cycle to simplify material flow

To address the long-term improvement needs of the current WIP Area in VS 1.0, the implementation of the Mizusumashi Train system operating on the Milk Run logic has been identified as a promising solution. The Mizusumashi Train and Milk Run concepts, both rooted in Lean Manufacturing, aim to streamline internal logistics and ensure that material flows are managed with precision, efficiency, and minimal waste.

The **Mizusumashi Train System** is a method of internal material handling that involves a dedicated vehicle (the Mizusumashi Train) following a predefined loop within the factory to deliver necessary components and materials to different workstations or production lines. The train operates in a continuous and predictable cycle, minimizing the need for manual transportation of materials by operators or forklifts, and ensuring that production lines are consistently supplied with what they need, when they need it. Mizusumashi is responsible for transporting parts to the assembly line and circulating a predetermined route without interruption. Tray containers are used for parts storage on an assembly line, and part containers are used for storing parts in a parts store. On the assembly line, empty tray containers are collected at the time of the Mizusumashi survey, and two or more empty tray containers may be collected at the same time.
In the following picture (5.4) is represented an example Mizusumashi Train system:

Figure 5.4: Explaining image of a Mizusumashi Train system

In this system, the “Fixed Withdrawal Cycle Method” is adopted, in which parts are recovered and replenished at time intervals determined for each part [27].
The key aspects of the Mizusumashi Train System include:

- Fixed routes: the train follows a consistent path throughout the factory, stopping at designated areas to pick up and drop off materials.
- Cyclical schedule: the system operates on a regular cycle, meaning that materials are delivered and retrieved at predictable intervals, ensuring a steady flow.
- Reduced traffic and congestion: by having a dedicated train handle the movement of materials, the system reduces the need for operators and forklifts

to move around the production area, leading to a safer and less congested workspace.

The **Milk Run System** is a logistics strategy that involves regular, scheduled pickups and deliveries of materials along a fixed route. The name "Milk Run" comes from the old practice of milk delivery services, where a truck would make scheduled stops to deliver and collect empty bottles in a loop, returning to its starting point once the route was completed. In a manufacturing context, the Milk Run ensures that materials are delivered to the production lines in a timely manner, based on the actual needs of the process, often aligned with Just-In-Time (JIT) principles [2.3.1]. Key components of the Milk Run System include:

- Efficient replenishment: the Milk Run ensures that only the required materials, in the right quantities, are delivered to the workstations, preventing excess stock buildup and minimizing WIP levels.
- Route optimization: the Train or vehicle follows an optimized path to reduce the travel time and distance between different areas of the factory.
- Improved resource allocation: since materials are replenished based on real-time needs, operators can focus on their tasks rather than worrying about stock levels, leading to smoother production flow.

In this logic two equations are used to maintain the balance between material flow, storage, and production demand.

$$No.\,of\ Boxes = RoundUp(\frac{2 * Milk\,Run\,Cycle\,Time}{Consumption\,Takt * Pieces\,per\,Box}) \tag{5.1}$$

This formula (5.1) is essential for determining how many boxes or containers are needed to transport materials during the Milk Run cycle or Mizusumashi Train route, ensures that boxes are scheduled for delivery just in time, aligning with production demand.
The key parameters are:

- **Milk Run Cycle Time:** the time required to complete one round-trip, which includes collecting empty containers from each workstation, delivering full ones, and the movement time between stations.
- **Consumption Takt:** the rate at which materials are consumed by the production line.
- **Pieces per Box:** the number of pieces per container.

By calculating the required number of boxes, you can ensure that the production line has the right amount of material without overstocking, reducing waste and improving efficiency.
Focusing on consumption takt it's possible calculate it through the equation:

$$Consumption\,Takt = \frac{Time\,Interval}{Demanding\,during\,Time\,Interval} \tag{5.2}$$

The earlier formula (5.2) helps to calculate how fast materials are being consumed in relation to the available time, providing insight into how frequently the Mizusumashi Train should run to supply the production line, considering:

- **Time Interval** is the time period over which you measure material consumption.
- **Demand during Time Interval** represents how much material is needed during that time.

This equation defines the rate of consumption (takt) of materials based on demand over a given time interval. The Consumption Takt indicates how often a material or component is required by the production line.

The design and dimensioning of the Logistic Train were key steps in optimizing material flow within the WIP Area for both the Riello 20 kW heat exchanger and the Burner.
Hereinafter are listed the key factors and calculations involved in determining the appropriate capacity, frequency, and structure of the Logistic Train, ensuring efficient material supply aligned with JIT principles and minimizing excess inventory.

1. **Calculation of component consumption rate:** the first step in the design of the logistics Train is to determine the material consumption rates and demand patterns for each workstation along the production line. To calculate that I have assumed as a Time Interval the duration of a work shift 7,5 hours (that amounts to 27.000 seconds) and as a Demand during Time Interval the production capacity of the assembly line in the same period of time (that is equivalent to 350 pieces or 400 pieces depending on the assembly line involved): from the ratio of two parameters it was possible to calculate the Consumption Takt for each part of the finished element (an example of a number of different element considered is illustrated in BOM of finished product (4.3)).

2. **Capacity and load calculation:** the train's capacity was calculated based on the total material volume needed for each delivery cycle. To quantify the volume of material transported for each cycle of the Logistic Train it was necessary to consider the number of pieces that make up the final assembly (this has been taken into account for each element of the finished product), and the value of the Pieces per Box, that corresponds to the number of components that are contained in each unit of stacking.

3. **Calculation of Milk Run Cycle Time:** once the rate of consumption of materials in assembly lines was determined, it was necessary to quantify the

duration of Milk Run Cycle Time. This Cycle Time represents the total time taken for the Logistic Train to complete a full circuit of material pickups and deliveries and must ensure the reordering of orders to various assembly lines without supply delays which would generate production delays.
The total time for one complete trip or "run" of the Logistic Train, encompassing:

- Pick-up and Drop-off Times: the time needed for the train to stop, unload full containers, and collect empty ones at each workstation.
- Movement Time: the time spent traveling between workstations and back to the starting point.

Taking into account the loading and unloading times of the various components, it was concluded that a Milk Run Cycle Time of **8.100 seconds** is sufficient to supply 4 different orders for all the assembly stations.

4. **Determining number of vehicles and carts:** based on the calculated Consumption Takt of the various components, and the data about the Pieces per Box for the single pieces, it is possible to calculate the number of packing units per component delivered to the lines from the Logistic Train with the equation (5.1), and this information is used to determine the optimal number of vehicles and carts for the Logistic Train. The study showed that a cycle time of 8.100 seconds results in one unit pack for each item (except in some cases where you need to bring 2 or maximum 3 packaging units for each item). This implies that the Mizusumashi Train has a maximum of **6 wagons**, 5 of these dedicated to pallet seats of the most voluminous elements, while the sixth wagon would be dedicated to a shelving in which they will be inserted small packages.

5. **Route design and Cycle Time determination:** once the dimensioning of the Logistic Train is completed, the study is completed with the tracking of the most efficient route through the production area for both the heat exchanger and burner production lines. The route was optimized to minimize travel time while covering each workstation in sequence, balancing proximity and material flow requirements. the Mizusumashi Train route is represented in the following image (5.5), where the Train route is simulated for supplying to all assembly lines that are working on 4 different orders, and the WIP Area with storage stations haves been dimensioned in order to guarantee a sufficient space of manoeuvre to the Mizusumashi Train.

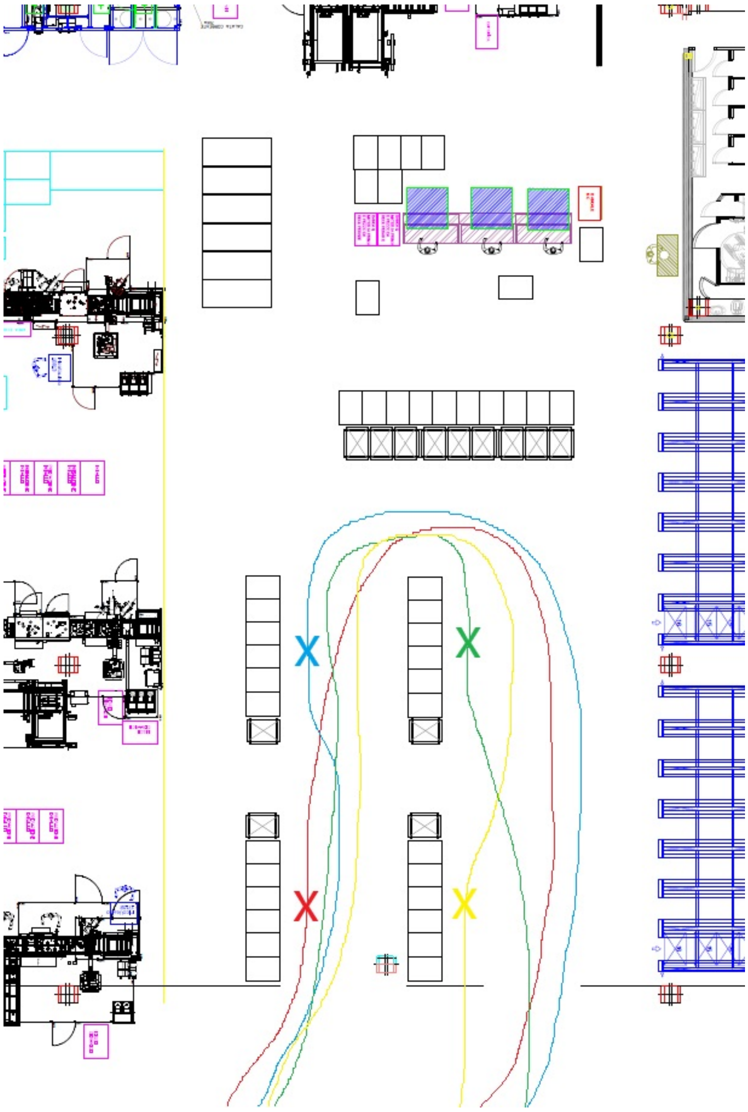


Figure 5.5: The route of Mizusumashi Train for four different orders

In the optimization of the material supply system for the WIP Area, a structured route was designed for the logistic train, allowing it to efficiently serve four different production orders. Each route is marked in a distinct color, representing a separate order, to clarify the flow of materials and ensure precision in the supply chain within the facility.
Cycle process overview of the logistic Train is illustrated below:

1. Material collection from SEV: the Logistic Train initiates its cycle by loading materials at the main SEV Warehouse. Here, the materials are organized based on the demands of each assembly line (according to the logic of Consignment Stock [4.2.2]), ensuring a tailored supply for each of the four production orders.

2. Route execution and stops in the WIP Area: after loading, the train follows a predetermined route through the facility to reach the WIP Area. As the

train enters the WIP Area, it makes stops at specific locations marked by "X" symbols in image (5.5). These stops represent strategic locations where the Logistic Train unloads fresh materials and collects empty containers for each of the four production orders, aligned with a particular assembly line's requirements:

- Delivery of supply materials: at each "X" point, the train unloads the necessary materials for that station, providing each assembly line with the exact components needed for the next stages of production.
- Collection of empty containers: simultaneously, the train collects empty containers that have accumulated at each stop, thereby clearing space for production and ensuring that materials do not clutter the workstations.

3. Return to SEV Warehouse: after completing its deliveries to all designated WIP points, the logistic train returns to SEV, where it unloads the empty containers and prepares for the next cycle.

4. Serving all four assembly lines: this cycle is repeated across all four color-coded routes, each corresponding to one of the four assembly lines. By having specific routes for each line, the logistic train can serve multiple production areas without confusion or cross-contamination of materials

The supply cycle just explained enables smooth transitions between tasks, minimizing potential errors in material allocation and allowing for a structured, uninterrupted workflow.

In the future WIP Area of VS 1.0, the introduction of the Mizusumashi Train operating under the Milk Run System can address several critical issues related to material flow, congestion, and inventory management. By delivering materials in smaller, more frequent batches, the Mizusumashi Train reduces the need for excessive stockpiling in the WIP Area, which in turn alleviates congestion. The calculated number of boxes, ensures that only the necessary amount of material is delivered at any given time, minimizing the space required for storage.
Additionally, the synchronization of the Milk Run cycle with production demand leads to an improved and continuous flow of materials, ensuring that materials are delivered just in time for production without causing delays and optimizing the use of the available space.

Despite its potential benefits, the implementation of the Mizusumashi Logistic Train system will not occur in the immediate future due to several prerequisites that need to be addressed within the company. Firstly, a specialized software system must be introduced to optimize production orders based on the capacity of the logistic train, ensuring that each load aligns precisely with production demands. Additionally, a continuous 24-hour supply system will be required to reliably feed the assembly lines without interruption, which may involve new infrastructure and procedural changes.

Moreover, It requires significant infrastructure changes, such as dedicated routes for the train, synchronization with production schedules, new spaces for the storage of materials, the use and implementation of new supply software and the recruitment of new personnel.
Finally the company must bear the full financial investment required for this transition, including the purchase of the logistic train, wagons, the associated equipment necessary for material transport and the staff training costs. These considerations, encompassing both technological and financial requirements, mean that the transition to the Mizusumashi system will require careful planning and investment before it can be fully realized.

5.2 Value Stream Mapping: Key Results and Strategic Improvement Proposals

After introducing in Chapter [4] the Value Stream Mapping (VSM) for the VS 1.0 process, providing a detailed explanation of its various branches and how they relate to the overall flow of materials and information within the production system, now I will focus on the critical areas of waste and inefficiencies that emerged from the VSM analysis. These weaknesses represent the main obstacles to achieving leaner, more efficient production and are identified in the VSM by Kaizen Bursts [4.6].
After identifying these key issues, using the **Future State Map** I will propose targeted improvement solutions designed to optimize the flow, reduce waste, and enhance overall productivity within the VS 1.0 system.
The Future State Map represents the final stage of the Value Stream Mapping (VSM) process. It is a visual representation developed from the analysis of the Current State Map, illustrating the optimal or "ideal" state of the process. The purpose of creating a Future State Map is to highlight areas where waste is being generated and to propose improvements aimed at reducing, managing, or ideally eliminating these inefficiencies [28]. This map serves as a guide for implementing lean principles to enhance productivity and streamline operations beyond the current state.

5.2.1 Analysis of the VSM and Future Improvement Strategies for the Riello 20 kW production process

The analysis of the Value Stream Map (VSM) for the production of the Riello 20 kW heat exchanger highlights several inefficiencies and areas of waste within the current manufacturing process. These problems represent potential areas for waste reduction through the application of Lean Manufacturing principles.
In the following image (5.6) the criticalities found in the VSM of Riello 20 kW are highlighted and explained by Kaizen Bursts (4.6).

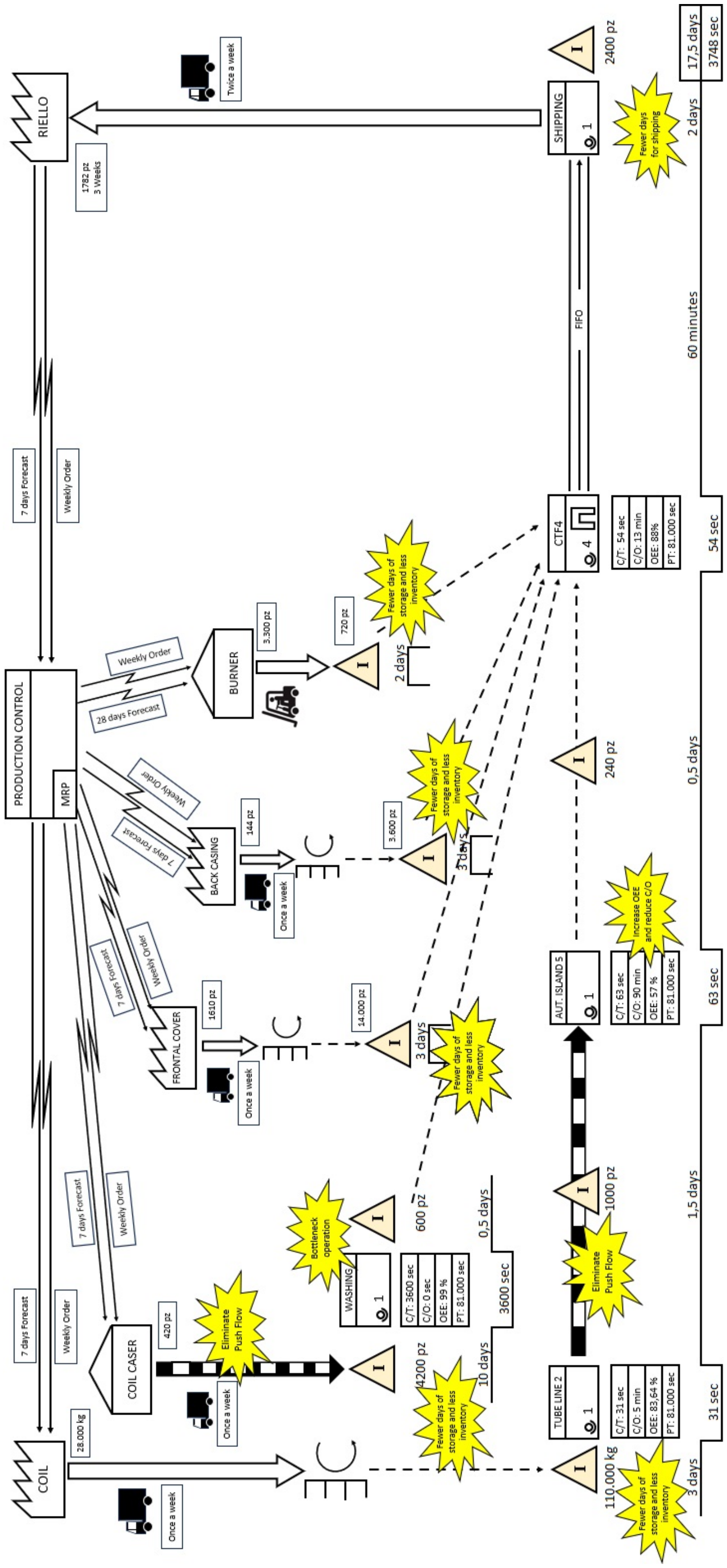


Figure 5.6: VSM of Riello 20kW with the Kaizen Bursts

These criticalities can be broadly categorized into three main areas: excessive inventory, long lead times, and equipment inefficiencies. Each of these issues contributes to unnecessary waste in terms of time, materials, and resources, which in turn reduces the overall efficiency of the production system.

1. **Excessive intermediate inventory levels**

   Inventories at various points in the process are particularly high, indicating stockpiles that generate waste of space, costs and delays in the production cycle:

   - Coil: 110.000 kg of stored product.
   - Coil Caser: 4.200 pieces of stored product.
   - Frontal Cover: 14.000 pieces of stored product.
   - Back Casing: 3.600 pieces of stored product.
   - Burner: 720 pieces of stored product.
   - Shipping: 2.400 pieces of stored product.

   These large quantities of waiting stock create waste of type Muda (Overproduction) and Muda (Waiting) [2.3.1], because before being used in the next working station, the materials remain stationary without added value.

2. **Long Lead Times and waiting periods between phases**

   The waiting times between the various stages of the process are very high:

   - Coil: 3 days of waiting before being used.
   - Coil Caser: 10 days waiting.
   - Frontal Cover: 3 days waiting.
   - Back Casing: 3 days waiting.
   - Burner: 2 days waiting.
   - Shipping: 2 days waiting.

   The consequence of having excessive non-value-added activities is a significantly elevated Total Lead Time (TLT) in the production process. This is a clear waste of Muda (Wait) [2.3.1]. The high level of non-value-added activities is primary factor that significantly reduces the VAR [4.2.1] in the Riello 20 kW production process.

3. **Low Overall Equipment Effectiveness (OEE)**

   The performance of equipment, especially Automatic Island 5 [3.4.2] with an OEE of 57% indicate significant inefficiencies related to failures, long setups or poor quality. This is a waste of Muda (Defects) or Muda (Overload) [2.3.1], since the efficiency of the equipment is not optimized.

4. **Long setup (C/O) on some machines**

   The setup time on Automatic Island 5 is 90 minutes, much longer than other processes. This introduces a considerable waste of time and potentially impacts on the entire production flow.

In the analysis of the VSM of Riello 20 kW production process (4.10), a critical observation emerges from the comparison between Value Added Time (VAT) and Total Lead Time (TLT): the TLT amounts to **17,5 days**, while the actual VAT totals only **3.748 seconds**. This stark contrast reveals a substantial imbalance, where a significant portion of the process is consumed by activities that do not contribute to the creation of value. These include waiting times, unnecessary material handling, bottleneck operation and excess inventory.
This leads to a lower value of VAR of **0,248%**, indicating that a smaller portion of the total time spent in the production process is dedicated to value creation.

In this context, the introduction of an integrated Kanban system with the use of supermarkets is a powerful solution to reduce the inefficiencies highlighted by VSM. The Pull-based Kanban system [2.5.2] regulates the flow of materials through production according to actual demand, eliminating overproduction and reducing excess inventory. Supermarkets act as controlled buffers, limiting the amount WIP and facilitating more flexible and responsive production.

The implementation of an integrated Kanban system with supermarket is an effective solution to address the inefficiencies revealed by the analysis of the VSM for both the Riello 20 kW heat exchanger and the Burner.
In the configuration of a Supermarket Pull System, each production process has a warehouse, called **Supermarket**, which contains a fixed quantity of each product made. The basic principle of this system is the supply: each process produces only to replace what is taken from the supermarket downstream [29].
Supermarkets can be considered as a set of parallel FIFO (First-In-First-Out) lanes [4.2.1], one for each type of component produced within the system. The flow of materials in a supermarket is very similar to that of FIFO aisles, with the only difference being that the flow is divided according to the type of part. However, the flow of information within a supermarket is more complex than with a pure FIFO system. Whenever a part is picked up from the supermarket, information about the removed part must be transmitted back to the beginning of the cycle, in order to start the replenishment of that specific part. This flow of information is regulated by a signal called **Kanban**.

Kanban (literally "billboard" or "sign" in Japanese) is a specific inventory control system, widely used in high-volume production lines to optimize material flow and reduce costs. It is based on the use of a series of coloured labels which act as visual signals to monitor the movement and production of components. As you can plainly see in the picture below (5.7), these tags contain essential information such as the quantity of parts, type of part and manufacturer, a unique barcode ID, part description and quantity, storage location, and designated usage area and are placed inside containers or batches of manufactured products [29].

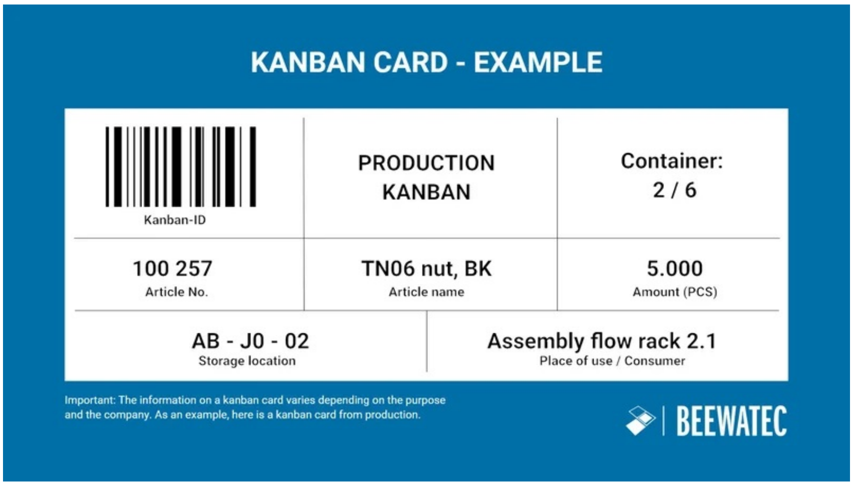


Figure 5.7: Example of a generic Kanban card

The main function of the Kanban system is to reduce production costs and time by maintaining visual control over inventory and ensuring a balanced and continuous flow [29]. Thanks to the Kanban system, each stage of the production process has a clear indication on what and how much to produce or move, optimizing the use of resources.

There are two main types of Kanban, which perform complementary functions and the graphic representation of these two different types of Kanban is illustrated in the image (4.6):

- **Withdrawal Kanban:** its main function is to authorize the movement of parts from one stage of the production process to the next. This tag accompanies the pieces during their movement and is returned to the previous stage once the pieces have been consumed, thus starting a new supply cycle.

- **Production Kanban:** this tag, on the other hand, has the task of ordering the production of a specific quantity of products in the previous stage of the process. Once the required parts are exhausted, the Kanban of Production signals the need to start a new production.

The six Toyota Rules [2.2] for efficient use of Kanban outline the key principles to ensure the success of the system:

- The next step takes the number of articles indicated by the Kanban in the previous step.

- The previous step produces articles in the quantity and sequence indicated by the Kanban.
- No item is produced or transported without a Kanban.
- A Kanban must always be attached to the goods.
- Defective products are not sent to the next stage, ensuring a defect-free production.
- Reducing the number of kanbans increases the system's sensitivity, making it more responsive to changes in demand.

However, it is necessary to consider that running a supermarket, compared to a simple FIFO lane, requires more attention and complexity in the initial configuration. In particular, it is necessary to determine the optimal number of Kanban for each type of component, an aspect that must be monitored and updated regularly to adapt to changes in demand and production times [24]. In addition, the system must be constantly checked to prevent any Kanban leaks that could compromise the synchronization of the production flow.
Furthermore, there is an inherent disadvantage in a supermarket system: each process must maintain an inventory for each of the parts it produces. This can become problematic if the number of article codes (part numbers) is high, as it would require complex management of a wide variety of stocks [29].
The following discussion will not deal with the dimensioning of the Kanban system or the calculation of the number of cards necessary to ensure continuity of production due to the tight time of the training activity.

As a result of the analysis of the current VSM, the study continued in designing the Future State Map (FSM) for the production of the Riello 20 kW unit, the objective is to address and overcome the inefficiencies and bottlenecks identified in the current process and explained above. The FSM of Riello 20 kW illustrated in the next picture (5.8) incorporates improvements aimed at streamlining material flow, enhancing equipment performance, and optimizing lead times through a more organized Pull System with the integration of Kanban cards and supermarket buffers.

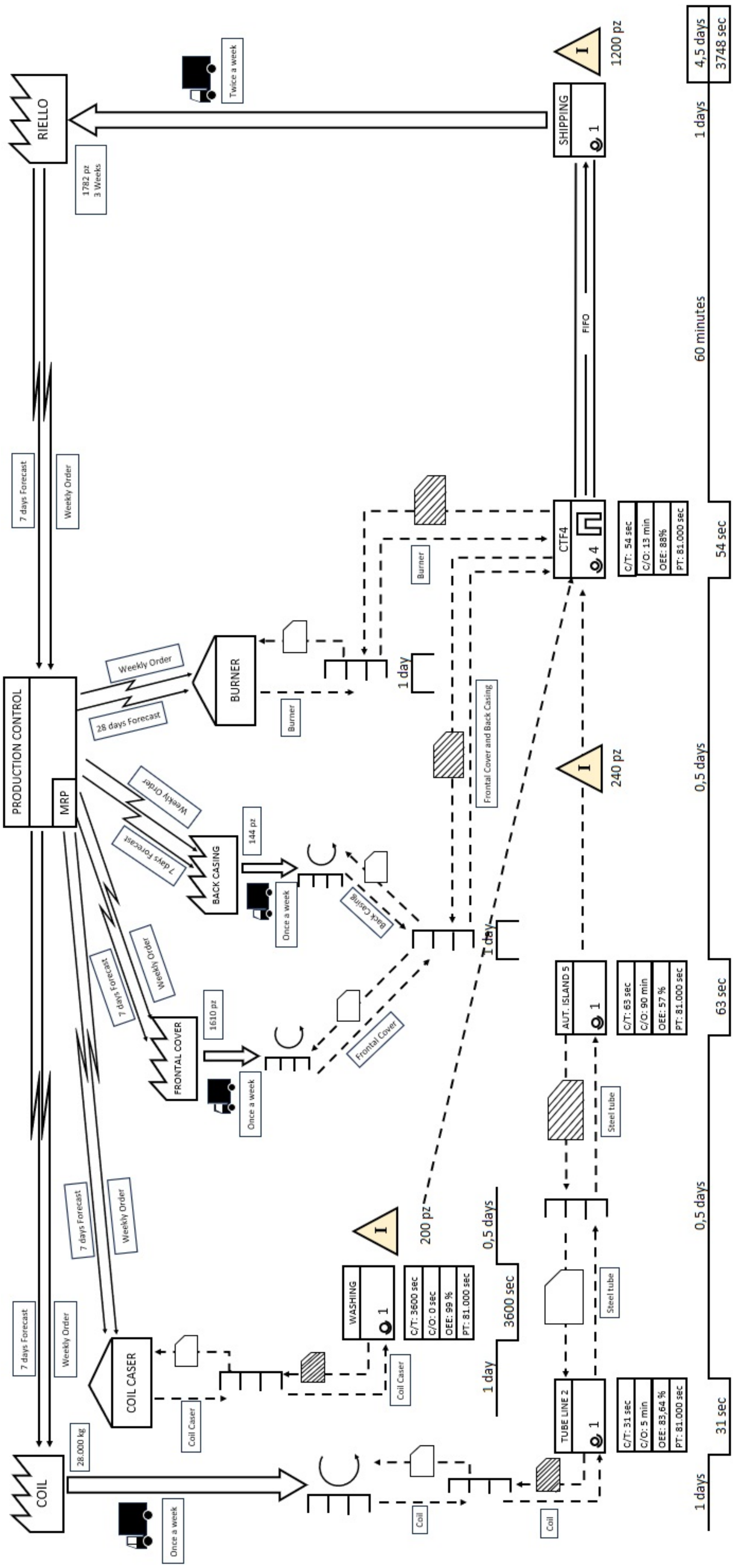


Figure 5.8: Future State Map of Riello 20 kW

The changes focus on reducing lead times, lowering inventory levels, enhancing equipment effectiveness, and implementing a Pull-based workflow through supermarkets and Kanban cards.
Below is an analysis of the primary improvements which can be achieved by implementing the FSM, which aligns more closely with lean manufacturing principles:

1. **Implementation of Supermarkets and Kanban system**

   In contrast to the previous Push-based production model, the FSM of Riello 20 kW incorporates supermarkets at critical points and each supermarket functions as an intermediate storage point, from which materials are replenished based on real-time demand.
   Supermarket Kanban systems have been strategically placed at key points in the production flow to manage inventory and optimize the flow of materials between processes.

   - Between the Coil (stored in the magazine near thr VS 1.0) and Tube Line 2: as materials are consumed by Tube Line 2, a Kanban card signals the Coil magazine to replenish only the necessary amount.
   - Between the Tube Line 2 and the Automated Island 5: with the Kanban system in place, Tube Line 2 produces tubes only as required by Automatic Island 5, reducing unnecessary WIP buildup and ensuring that production flows at a balanced pace between these two stages and eliminating the Push flow of the previous VSM (4.10).
   - Between the production of Coil Caser and the step of Washing: this setup prevents excess inventory buildup and aligns production with real-time demand from CTF4.
   - Between the Frontal Cover/Back Casing Supply and CTF4: separate supermarkets for Frontal Cover and Back Casing are positioned before the assembly stages to buffer these components and synchronize their flow with the assembly line. This setup helps to maintain balanced production rates between component preparation and assembly and minimized inventory accumulation between these component suppliers and the assembly stages.
   - Burner Supermarket before CTF4: this supermarket prevents excess accumulation in the final assembly area and ensures a steady availability of Burners based on real-time consumption by the CTF4.

2. **Reduction of Lead Times and Inventory levels**

   The use of supermarkets and Just-In-Time replenishment [2.1.1] in the FSM reduces these Lead Times significantly. Through the utilization of Kanban cards to regulate material flow, components are produced or moved only when necessary. This Pull system reduces idle time for parts within the system and

decreases the inventory levels required to sustain continuous production.
Here's where and how these changes are evident:

- Reduction of Lead Times in the Coil supply to Tube Line 2: through the supermarket Lead Times have been reduced from 3 days to **1 day**, and moreover with the Kanban system, the Coils are supplied only when needed by Tube Line 2 reducing wait times and keeps the production line continuously supplied without overstocking.
- Optimizing Coil flow between Tube Line 2 and the Automated Island 5: the implementation of supermarket has helped optimize inventory levels by ensuring that only the necessary amount of tubes is produced and stored in the supermarket, ready for immediate consumption by Automatic Island 5. The result is the reduction of Lead Time from 1,5 days to **0,5 days**.
- Fewer time in preparing Coil Caser before washing: with the Kanban system the demand-driven approach minimizes the buffer inventory and reduce the Lead Time from 10 days to **1 day**, here means a quickly flow of the Coil Caser to Washing, supporting a smoother flow through the early stages of the process.
- Reduced Lead Times in supplying process to CTF4 for Frontal Covers and Back Casings: the introduction of supermarkets for Frontal Covers and Back Casings ensure a supplying alignment with the immediate needs of the assembly line, reducing both the waiting time and the overall lead time for each Burner assembly that decrease from 3 days to **1 day**.
- Streamlined the supplying of Burner: the supermarket before the Burner assembly stage has introduced a controlled buffer for partially assembled Burners, reducing WIP inventory: the result is a faster flow of Burners through the line, as they no longer have to wait in large queues before reaching final assembly and reduce the Lead Time from 2 days to **1 day**.

3. **Enhanced equipment utilization and OEE improvements**

   In the initial VSM, equipment such as Automatic Island 5 had a low OEE of 57%, attributed to extended setup times, occasional failures, and quality issues. In the revised VSM, setup and changeover times have been optimized for Automatic Island 5 and other key stations. This leads to better utilization of equipment and a higher OEE, contributing to an overall increase in process efficiency.

4. **Streamlined material flow and waste reduction**

   The previous VSM showed that inefficient flow pathways led to redundant movement and material waste, particularly in stages like Washing and Tube Line operations where materials frequently remained idle. The Pull system established in the FSM enables a continuous, streamlined flow of materials, minimizing unnecessary handling and wait times. This reorganization ensures that each part moves to the next process stage without delay, significantly reducing waste and increasing operational efficiency.

The analysis of the Value Stream Mapping process for the 20 kW Riello heat exchanger demonstrates significant improvements in operational efficiency when comparing the Future State Map (FSM) with the Current State.
Indeed, from the FSM it can be noted that the Total Lead Time (TLT) for the production of the heat exchanger Riello 20 kW has decreased from 17,5 days to **4,5 days**, while the while the Value Added Time (VAT) remained **3.748 seconds**: this means that the VAR is equivalent to **0,963%**, against the value of 0,247% in the Current State, with an increase value of VAR in FSM of **389%**.
This transformation underscores the potential of the FSM as a model for achieving both higher productivity and greater responsiveness to demand within the production process.

5.2.2 Analysis of the VSM and Improvement Strategies for the Burner production process

The analysis of the Value Stream Map (VSM) for the Burner production process highlights some inefficiencies and areas for improvement within the current workflow. This study identifies key issues such as excessive inventory levels, long lead times, and inefficient equipment utilization, which contribute to production delays and resource wastage.
The waste of production are labeled in VSM with Kaizen Bursts (4.6) as can be seen from the following image (5.9).

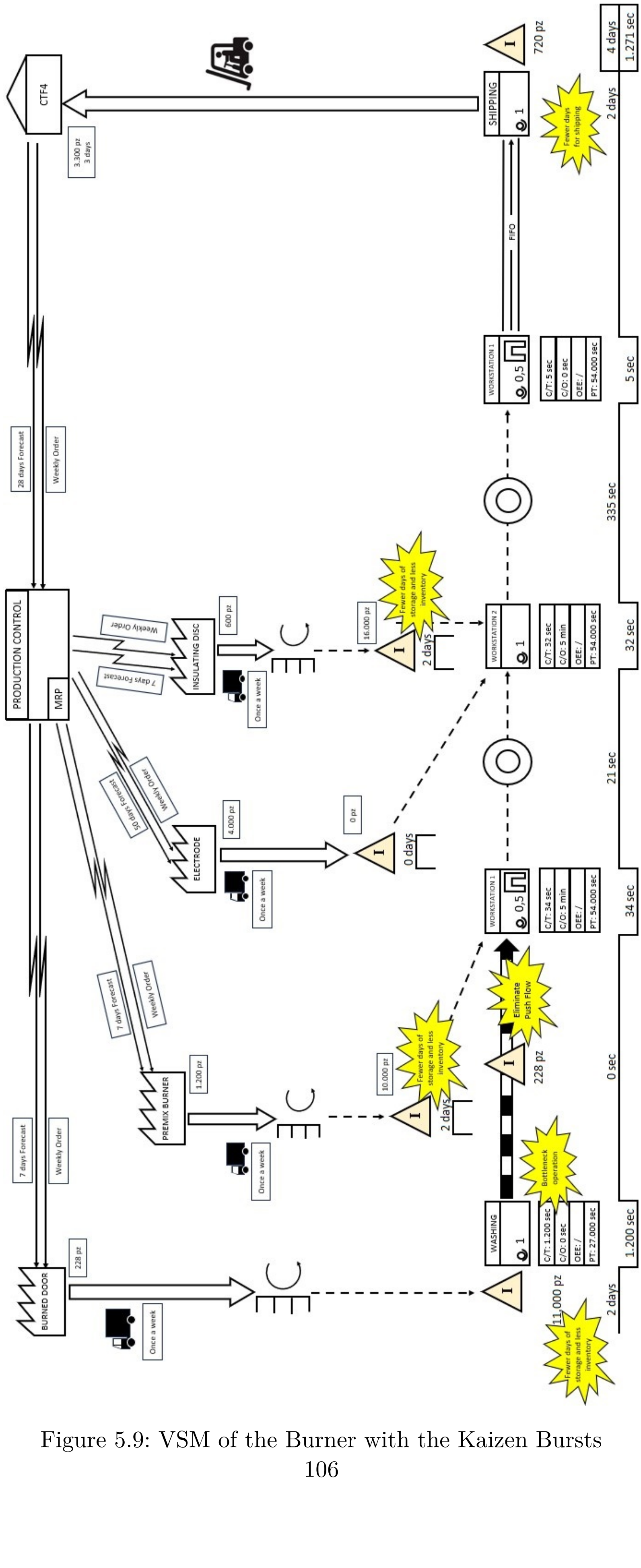


Figure 5.9: VSM of the Burner with the Kaizen Bursts

The map reveals critical bottlenecks, excess inventory, long lead times, and inefficient workflow patterns that contribute to delays and non-value-added activities. By addressing these issues through lean methodologies, it is possible to streamline the production process, reduce waste, and improve overall operational efficiency.

1. **Excess of Inventory**

   There are large stocks of components held at various stages of the process:

   - Burner Door: 11.000 pieces of stored product.
   - Premix Burner: 10.000 pieces of stored product.
   - Insulating Disc: 16.000 pieces of stored product. Such high levels of inventory indicate overproduction, which can tie up capital and resources, increase storage costs, and potentially lead to obsolescence or quality degradation over time.

2. **Long Waiting Times and extended Lead Time**

   The lead times for the overall production process are inflated due to the extended waiting times and excess inventory: consequently the entire production process is slowed down, resulting in inefficiencies.

   - Burner Door: 2 days of waiting before being used.
   - Premix Burner: 2 days of waiting.
   - Insulating Disc: 2 days of waiting.

   These waiting times extend the total lead time unnecessarily and add no value to the product.

3. **Lack of Overall Equipment Effectiveness (OEE) data**

   There is missing information on the OEE for critical workstations: without this data, it is difficult to assess how well these machines are performing. Potential issues such as unplanned downtime or low productivity may be going unnoticed, leading to further delays and reduced throughput.

4. **Presence of a bottleneck process within the operation**

   As we can see, the cycle time of the washing station is significantly higher than the Takt Time, with a cycle time of **1.200 seconds** compared to the **49 seconds** imposed by Takt Time needed to meet demand [4.2.2]. This is a clear bottleneck in the process. Although the other stations have cycle times lower than the Takt Time, this discrepancy in the Washing station causes a general slowdown of production.

In summary, the study of the Burner's VSM reveals a production process that suffers from excessive inventory times, bottlenecks, and imbalanced workflow. These factors result in a Total Lead Time (TLT) of **4 days** that is overwhelmingly composed of non-value-added time, while the activities of Value Added Time (VAT) amount to a total of **71 seconds** (the 1.200 seconds needed to wash are not taken into account because they are not considered as value added time): this leads to a very low Value Added Ratio (VAR) which amounts to **0,0205%**.

Continuing the analysis of the current state map of the Burner production line and the identification of key inefficiencies, the Future State Map (FSM) has been developed to address these critical issues and guide the line towards a leaner, more efficient workflow. The FSM focuses on eliminating bottlenecks, reducing excessive lead times, and optimizing inventory levels through the implementation of lean methodologies, particularly the Kanban and supermarket systems. These tools are strategically applied at specific points in the production process highlighted by Kaizen bursts in image (5.9) to create a smoother flow, improve responsiveness to demand changes, and reduce waste.
The following image (5.10) outlining the ideal future workflow, aiming for streamlined operations, higher quality output, and reduced costs.

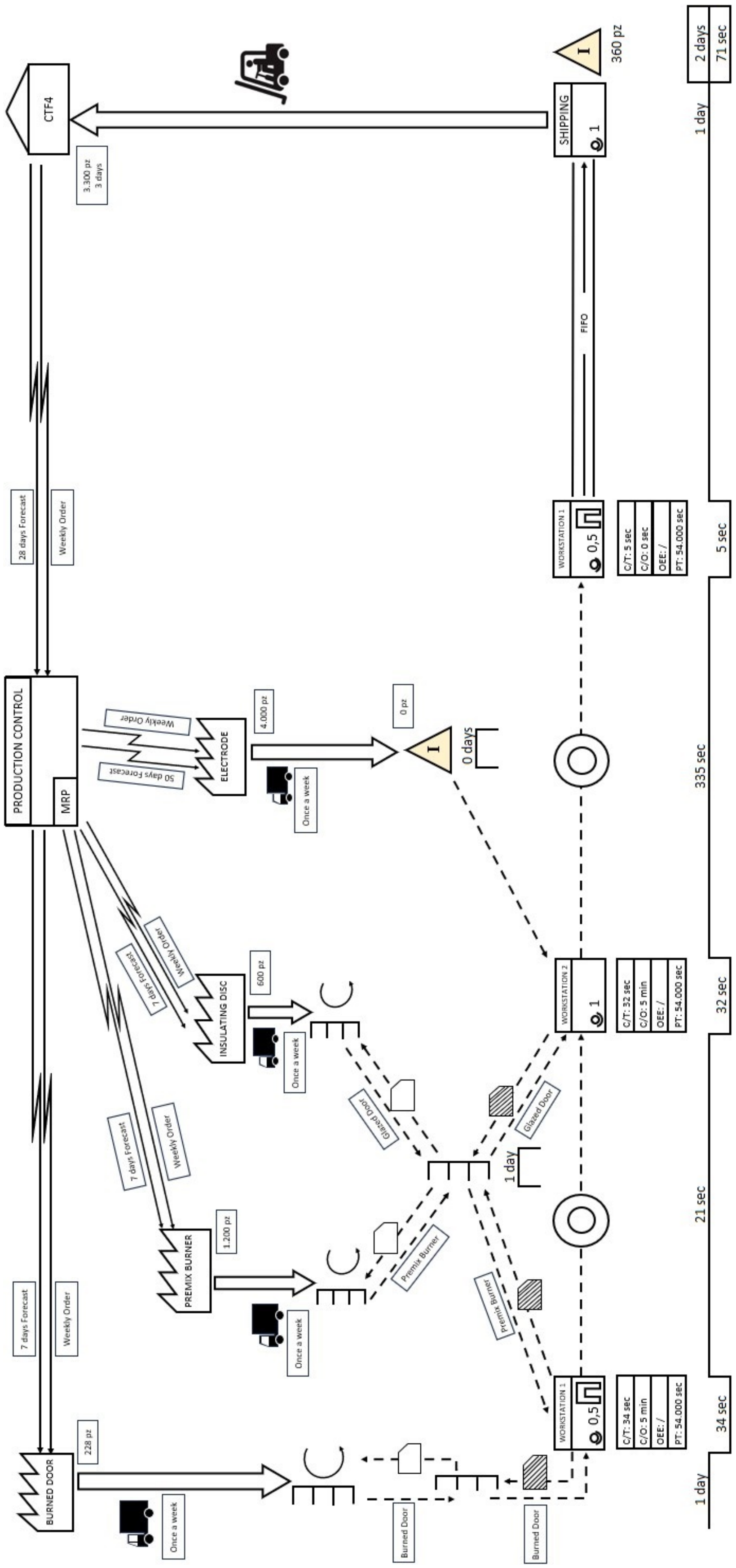


Figure 5.10: Future State Map of Burner

In analyzing the Future State Map (FSM) for the Burner production line, several targeted improvements have been implemented over the current VSM.
Here's an overview of the key enhancements achieved in the FSM compared to the initial state:

1. **Implementation of Supermarket and Kanban Systems**

   Also in this case Supermarket and Kanban systems have been strategically placed at key transition points to enhance flow, reduce overproduction, and improve responsiveness to demand.
   Here's how they function between specific steps:

   - Between the Burned Door (stored in the SEV magazine) and Workstation 1: a supermarket is implemented here to serve as a buffer, holding a controlled amount of Burned Door components. A Kanban card system is employed to signal replenishment.
   - Between the Insulating Disc and the Premix Burner (stored in the SEV magazine) and Workstation 1 and Workstation 2: another supermarket is established at this point, stocked with Insulating Disc and Premix Burner components. This controlled stockpile ensures that Workstation 1 and Workstation 2 have access to parts only when necessary, avoiding bottlenecks due to unavailability or overproduction of Insulating Discs. The Kanban system here functions similarly. This Pull mechanism allows production of Insulating Discs only in response to demand from Workstation 1 and Workstation 2, maintaining lean inventory levels and optimizing flow.

2. **Reduction in Lead Time and Inventory Levels**

   The FSM reduces Lead Time and inventory levels by optimizing each transition point to eliminate delays and prevent excess accumulation of components.
   Here's how these improvements manifest across the different production stages:

   - Between the Burned Door supplier and Workstation 1: in the FSM, with the supermarket in place, Burned Doors are pulled as needed by Workstation 1, ensuring that inventory is kept at a minimum. This Pull system reduces lead time by avoiding large stockpiles and only moving items when demand requires it. The supermarket holds just enough Burned Door parts to keep production flowing without delays, reducing Lead Time required to sustain Workstation 1 from 2 days to **1 day**.
   - Between the Insulating Disc and Premix Burner supplier and Workstation 1 and Workstation 2: the introduction of a supermarket between the Insulating Disc and Premix Burner supplier and Workstation 1 and Workstation 2 controls inventory levels by storing only what is necessary for immediate demand. Instead of maintaining a high inventory buffer

to cover potential delays, the supermarket allows Insulating Discs to be stored temporarily until Workstation 2 is ready for them and this results in a reduction of Lead Time from 2 days to **1 day**.

3. **Elimination of the Washing phase**

   In the FSM of the Burner production line, the Washing step has been eliminated because it was identified as a non-value-added activity that did not contribute directly to the final product's quality or functionality (in fact the washing time was not included in the value added time [4.2.2]. Furthermore, the washing phase had previously been identified as a bottleneck in the production flow. As a result, eliminating this stage contributes directly to achieving a leaner, faster production process, ultimately benefiting both efficiency and throughput in the Burner assembly.

The FSM for the Burner production process represents a meaningful advancement in efficiency compared to the Current State. With a TLT of **2 days**, against a TLT of 4 days in the Current State, and with a VAT of 71 seconds, the value of the VAR for the Future State is equivalent to **0,0411%**, that in comparison to the value of 0,0205% of the Current State corresponds to an increase of **200%** of the value.
This enhanced VAR reflects a leaner, more responsive, and cost-effective process, showcasing the value of continuous improvement initiatives within the manufacturing environment. The FSM for the burner thus serves as a robust model for optimizing production efficiency and achieving lean objectives.

The table below (5.1) lists the current (AS-IS) and projected (TO-BE) values of the VAR parameter for Riello 20 kW and Burner. The comparison highlights the expected improvement after implementing lean strategies. The aim is to reduce variability and enhance process efficiency through targeted actions.

Component	**AS-IS**	**TO-BE**
VAR Riello 20 kW	**0.247%**	**0.963%**
VAR Burner	**0.0205%**	**0.0411%**

Table 5.1: Comparison of VAR values before (AS-IS) and after (TO-BE) lean improvements for Riello 20 kW and Burner.

Chapter 6

Conclusion

In this concluding chapter, we reflect on the findings and implications of this research, summarizing the journey taken through the application of Lean Manufacturing principles at VALMEX S.p.A. The analysis not only underscores the relevance of Lean tools in enhancing production efficiency but also provides actionable insights tailored to the specific needs of the heat exchanger industry.
This thesis has systematically explored the integration of Lean Manufacturing principles within the operations of VALMEX S.p.A., focusing on the production processes for heat exchangers. In particular, in Chapter [4], the application of Lean analysis tools, such as Spaghetti Charts and Value Stream Mapping (VSM), revealed critical areas of hidden waste within the internal logistics flows of the Circond 1.0 production line. This analysis laid the groundwork for Chapter [5], where specific proposals for process improvements were formulated, addressing the identified inefficiencies. These proposals were designed to optimize workflows, enhance product quality, and ultimately align with the company's strategic objectives.

The application of Spaghetti Charts within the value stream of the Riello 20 kW heat exchanger has yielded significant insights into the operational inefficiencies present in VALMEX S.p.A.'s production process. Through this analysis, critical challenges were identified, including the lack of designated areas for incoming and consumed materials, the presence of congestion points along movement paths, and the absence of specific zones for empty pallets. In response to these challenges, a set of targeted improvement proposals has been developed, focusing on streamlining material flow and enhancing workplace organization. These proposals emphasize the necessity of decongesting high-traffic areas, establishing clear zones within the WIP environment, and ensuring that only essential materials are present on the production floor. Moreover, creating separate corridors for operators and forklifts is crucial in enhancing safety and efficiency in daily operations.
To implement these improvements effectively, two strategic solutions were proposed. The short-term solution involves a redesign of the WIP Area layout, featuring 4 distinct proposals aimed at optimizing space and material flow. This immediate step is important for mitigating the congestion issues identified in the analysis. In contrast, the long-term solution centers on the introduction of a logistical system based on a Milk Run Cycle, where the Mizusumashi Train would supply all four

assembly stations every 8.100 seconds, effectively provisioning each station on a regular schedule. This logistical approach, equipped with 6 wagons, 5 dedicated to larger items and 1 for smaller packages—offers a comprehensive method for improving material handling and overall production efficiency.

The application of Value Stream Mapping (VSM) to the production processes of the Burner and the Riello 20 kW heat exchanger has revealed significant inefficiencies and highlighted critical opportunities for improvement.
In the current state of the Burner production, excessive inventory times, bottlenecks, and imbalanced workflows resulted in a Total Lead Time (TLT) of 4 days, with a Value Added Time (VAT) of 71 seconds, emphasizing a dismal Value Added Ratio (VAR) of 0,0205%. The Future State Map (FSM) demonstrated that by implementing Supermarket and Kanban systems, we could reduce the TLT to 2 days, leading to a remarkable VAR improvement to 0,0411%, marking a 200% enhancement in operational efficiency.
Similarly, the analysis of the Riello 20 kW heat exchanger production process revealed a staggering TLT of 17,5 days compared to a VAT of just 3.748 seconds, which indicated a low VAR of 0,248%. By transitioning to a Kanban system with Supermarkets, the FSM indicated a reduction in TLT to 4,5 days while maintaining a VAT of 3.748 seconds, resulting in an increase in VAR to 0,963%, an improvement of 389%. These results not only underscore the innovative potential of Lean methodologies but also emphasize the importance of systematically addressing inefficiencies in production processes. By implementing the identified improvements, VALMEX S.p.A. can significantly enhance its operational efficiency, reduce waste, and bolster its competitive position in the market. Ultimately, this thesis demonstrates that the strategic application of Lean principles through tools such as VSM and Kanban can lead to substantial advancements in process optimization and overall productivity.

In conclusion, the comprehensive application of Lean principles within VALMEX S.p.A. has proven to be a transformative endeavor, yielding significant improvements across various production processes. By meticulously analyzing workflows through tools such as Value Stream Mapping (VSM) and Spaghetti Charts, the company has been able to identify critical areas of waste and inefficiency. The targeted implementation of Lean strategies, particularly the adoption of Kanban systems, Supermarket layouts and the use of Mizusumashi Train system, has not only streamlined operations but has also fostered a culture of continuous improvement.
In summary, the journey of integrating Lean principles has equipped VALMEX S.p.A. with valuable insights and practical tools for ongoing process optimization. As the company continues to evolve in a dynamic industrial landscape, the foundations laid by Lean practices will serve as a catalyst for future innovations and sustained operational excellence.

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