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"ENHANCING FLOW AND REDUCING WASTE: A LEAN RELAYOUT AT LOWARA S.R.L."

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Abstract

This thesis explores the lean transformation journey of Lowara S.R.L., a leading company in the production of hydraulic pumps, water treatment, and control systems, with a focus on the relayout of an assembly line using lean manufacturing principles.

The study addresses key issues such as high inventory levels, inefficient space utilization, and the need to meet production demands while trying to transition from two shifts to one.

The research begins by analysing the AS-IS situation, identifying inefficiencies in the existing assembly line layout, documenting the operational challenges faced by the company and mapping all the flows that are linked to the line. Using lean tools like Value Stream Mapping (VSM), continuous flow, poka-yoke, Kaizen, etc, the study proposes a comprehensive relayout designed to improve workflow, reduce waste, and optimize production capacity.

The TO-BE situation is presented as the target state, highlighting improvements in space utilization, inventory reduction, and enhanced production flow. The relayout is expected to align the company's operations with lean manufacturing principles, resulting in a more efficient assembly process that can meet demand with reduced shifts. The aim is to create and comprehend the logic of the "model cell", that will be then applied and suited to the other cells of the plant.

The findings demonstrate that the lean transformation not only improves operational efficiency but also contributes to sustainable growth by minimizing waste and maximizing value.

The thesis concludes with an analysis of the challenges encountered during implementation, lessons learned, and recommendations for further lean improvements at Lowara S.R.L.

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Introduction

Operational excellence, which requires the reduction and elimination of unnecessary waste to bring maximum value to customers, is now a necessity for manufacturing companies to survive in the growing competitive and resource-scarce industrial environment. Lean manufacturing techniques were born from the Toyota Production System; over the years, these have found themselves incorporated into nearly all types of industries as the way to improve overall performance through waste reduction and continuous process improvement. The central focus of this thesis is the application of lean principles at Lowara S.R.L., a leading producer of hydraulic pumps and water treatment systems, through the relayout of an assembly line in such a way that the created "model cell" would serve as proof of the efficiency of lean.

The operational transformation journey of Lowara deals with vital questions related to high levels of inventory, poor use of space, and confused flow of materials. An in-depth analysis based on the current AS-IS configuration outlines the inefficiencies within processes and develops a material flow map. Using a various set of lean tools, and the principle of continuous flow, this study proposes a target or TO-BE layout aimed at smoothing workflow and eliminating waste with optimized capacity of production.

The proposed model cell will serve as a reference for lean practices in other production areas, conforming to Lowara's goal of achieving a standardized and efficient production system.

Chapter 1

Xylem Inc. and Lowara S.R.L.

This chapter presents an in-depth analysis of Xylem Inc. (Figure 1.1), with a specific focus on the history and activities of one of its flagship brands, Lowara S.R.L. (Figure 1.2).

Located in Montecchio Maggiore, Vicenza, Lowara is a center of excellence specialized in the production of stainless-steel pumps. This chapter begins by outlining the vision, mission, and values that guide the entire Xylem Inc. organization, emphasizing its commitment to delivering innovative solutions in the sector.

Next, the chapter explores the various fields in which the company operates and the diverse applications of its products across multiple industrial sectors. This initial overview will set the stage for a deeper understanding of the challenges and opportunities that characterize the operational context of Xylem Inc. and Lowara S.R.L. in today's market.

Figure 1.1: Xylem Inc. Logo

Figure 1.2: Lowara S.R.L. Logo

1.1 Company History

In October 2011, Xylem was established as a result of the spin-off from ITT Corporation, a company specializing in technologies for water transport, treatment, and analysis.

Xylem derived its name from the Greek word "Xylema", which refers to the tissue in plants that transports nutrients and water from the roots of trees to the leaves. It designs, manufactures, and distributes solutions to cope with the needs of its customers throughout the whole water

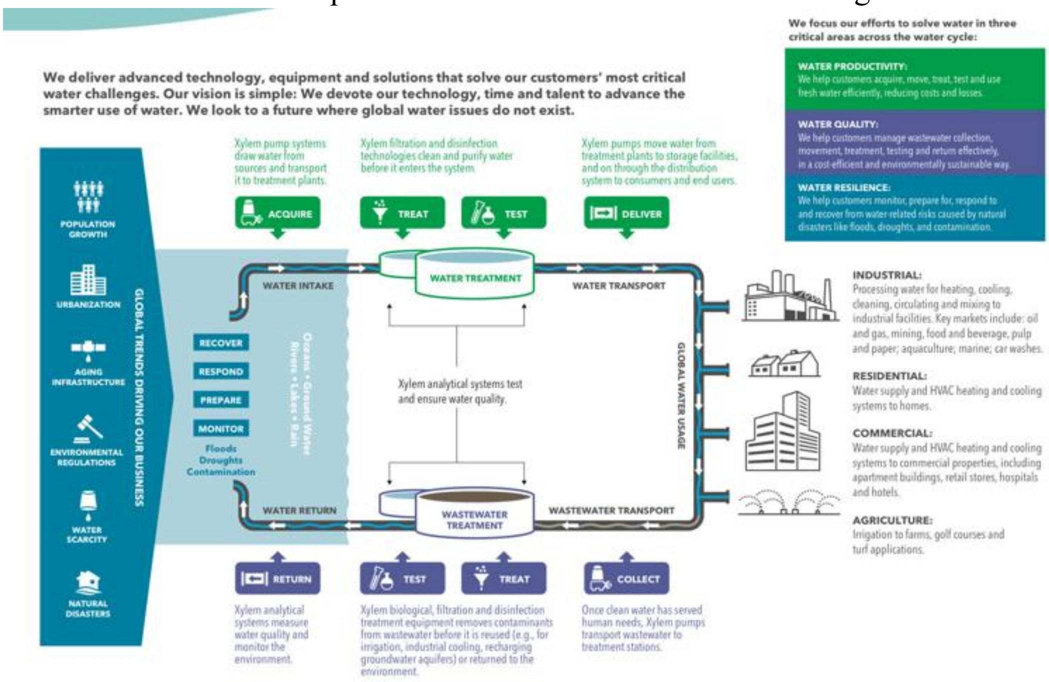

Figure 1.3: Xylem presence throughout the whole water cycle

cycle (Figure 1.3) and is committed to solving the most challenging water-related problems: treatment of water to make it potable, transportation where it is needed, using it in the most efficient way possible, testing and analyzing its quality, and cleaning it after the innumerable uses to which it is subjected.

Currently, Xylem is an American multinational publicly traded company and has its headquarters in New York.

It is the global premium brand in water technologies serving clean water and wastewater applications and operates in over 40 countries while selling in more than 150 nations with more than 360 locations and around 23,000 employees.

With revenues in 2023 of 8.3 billion $ and a CAGR of 6.2%, Xylem is a strong player in the market, laying is business strategy onto five major pillars:

Grow in the Emerging Markets: The company is actively enhancing its presence in emerging markets by investing in regional capabilities. It plans to grow its innovation, product management, and engineering teams in these regions, with a focus on expanding market reach in key growth areas such as China, India, Eastern Europe, Latin America, and Africa. By offering water and sanitation solutions tailored to local needs, the company aims to create new product portfolios and business models that serve the base of the pyramid population.

Strengthen Innovation and Technology: The company is looking to create new customer offerings that effectively address the water challenge and provide rapid, profitable growth opportunities. In developing and enabling the infrastructure for digital growth, it has worked towards the interoperability of hardware, networks, and software applications while building a single unified software experience. It will be developed to supplement core product offerings with strategic, sustainable innovation and insightful data analytics; this will aid in the exploration of new markets with advanced technologies and innovative business models.

Build a High Impact Culture: The company aims to embed the continuous improvement mindset across its operations as a significant drive to enhance efficiency by streamlining business processes and maintaining cost discipline in support of sustainable growth. It is committed to reducing the complexity of the business through the streamlining of internal bureaucracy, the extension of standardized business platforms and processes, thereby freeing up its employees to focus their energy on value creation for customers. Other focal areas include the removal of unnecessary costs from the end-to-end value chain to free up resources for growth and embedding resilience and sustainability within the supply chain to protect its capability to serve customers.

Cultivate Leadership and Talent Development: The company is under obligation to an inclusive, fair, and diverse culture that empowers all colleagues. The firm will continue building leadership succession depth and breadth in furtherance of its pledge for developing the next generation of leaders. It also intends to link its incentives-share-based and performance-based compensation-and organizational structure with its strategic objectives in fostering a single company culture of value creation for stakeholders.

1.2 Distribution of Market by Sector

The company operates in four principal business segments: Water Infrastructure, Applied Water Systems, Measurement and Control Solutions, and Integrated Solutions and Services.

- *Water Infrastructure*: The segment serves water intakes, treatment, and distribution, as well as wastewater treatment. Utilities and industrial facilities are the main customers, while product including pumps, filtration systems, and disinfection equipment. The segment represents 73% of its revenues from the Transport application and 27% from the Treatment application.

- *Applied Water Systems*: This segment provides solutions for water use in the residential, commercial, and industrial markets. Common products include pumps, valves, and heat exchangers. This market is divided, with 55% of revenues coming from Building Solutions and 45% from Industrial Water.

- *Measurement and Control Solutions*: This segment includes smart metering, data analytics, and communication devices used for efficient management of water and energy resources. Approximately 78% of revenues come from water-related applications, with the remainder generated by energy.

- *Integrated Solutions and Services*: this segment offers a wide range of lifecycle services in water treatment, filtration, and mobile water systems, serving various industrial and utility customers.

1.3 Geographic Profile

The company's geographical distribution spans four macro areas: the United States, Western Europe, Emerging Markets, and Other Regions.

- *United States*: 54% of revenues.
- *Western Europe*: 22% of revenues.
- *Emerging Markets*: Eastern Europe, the Middle East, Africa, Latin America, and Asia-Pacific, 16% of revenues.
- *Other Regions*: 8% of revenues.

Figure 1.4: Xylem brands

Xylem is presented as a single large company with a portfolio composed of around forty brands (Figure 1.4)

Among them is Lowara, recognized by the entire world for its pumping solutions in residential and industrial fields. In 2006, Lowara was acquired by ITT Corporation then and is now part of the AWS Growth Center of Xylem.

It was born in 1968 at Montecchio Maggiore (Vicenza) due to the intuition of the brothers Ghiotto. Lowara is a company that designs, manufactures, and distributes pumps and pumping systems related to water technology. It has always been dedicated to serving customers and users with a wide range of pumps for various application sectors.

It was particularly recognized as one of the most innovative companies in the hydraulic electric pumps, water control, and movement systems fields. The products offered by this company satisfy modern society, which is attentive to cost-efficiency, and are known and respected all over the world for their quality, safety, and reliability. It provides for excellent use of AISI 304 and 316 steel, making the products more secure and long-lasting and attesting to the company's commitment to technological innovation. By laser cutting and welding, the product will be more precise and timeless, characterized by correct and functional design with resistance to chemical aggression.

Finally, the advice, information, and assistance during the whole supply chain: speed, punctuality, and availability are the main features of Lowara's support service to its customers.

1.4 Xylem Vision

Xylem's vision is reflected in its commitment to five key stakeholders:

"Our Work: Water is essential to life. And our life's work is water. We transport it to places it needs to go, we treat it to make it clean, and we test it to ensure its quality. We focus on the world's most critical water challenges.

Our customers: Our customers are partners. They are the reason we succeed. We work to anticipate their needs with our broad product offerings and our applications expertise.

Our employees: Our employees are inspired to make a difference through innovation and influence. By focusing on water, we are dedicated to improving people's lives.

Our shareowners: Our shareowners expect us to create value. We strive to reward their confidence in us." (Vision & Values | Xylem US, n.d.).

1.5 Xylem Values

Xylem values are simple but effective, determining the everyday approach to what comes. They can be displayed trough four pillars:

Respect for each other, for diversity of people and opinions, for the environment.

Responsibility, for our words and actions, for customer satisfaction, for giving back to our communities.

Integrity for acting ethically, for doing what we ay we will do, for having the courage to communicate with candour.

Creativity for thinking beyond boundaries, for anticipating tomorrow's challenges, for unlocking growth potential. (Vision & Values | Xylem US, n.d.)

At Xylem, sustainability also plays a crucial role. It is integrated into all activities not only to address water-related issues but also to safeguard and enhance the company's long-term growth. In fact, the company aims for smart and responsible development. Targets are set regarding greenhouse gas emissions, energy efficiency of pumps, and the amount of water used to produce

them. At the end of each year, a report is compiled, showing the results achieved, which is accessible to all stakeholders.
By pursuing a policy of social responsibility, Xylem established *Xylem Watermark*, a corporate solidarity program whose mission is to provide and protect safe water resources for communities in need worldwide and educate people about water issues. Through Xylem Watermark, the company is committed to bringing clean water, sanitation facilities, and hygiene education programs to schools and communities in emerging countries, as well as providing water solutions in response to disasters and emergencies.

"Safety first" could be defined as one of Xylem's slogans, as the safety of all those working within the company is a top priority. The company's philosophy is to strive for zero workplace injuries and raise awareness among the entire workforce on this issue, stressing out the need of a powerful site communication.

1.6 Application fields

Xylem's Lowara brand leads in providing long term economical solutions for pumping and circulating both clean and contaminated water.

In residential and commercial construction, Lowara pumps are used for pressurization, air conditioning, drainage, and firefighting. The company manufactures single and multi stage stainless steel centrifugal pumps that guarantee high performance levels. The complete range of circulators and in-line pumps has been designed to meet the needs of the most innovative heating and air conditioning systems. The production also includes stainless steel drainage and sewage pumps, as well as lifting systems. Fixed and variable-speed pressurization systems are also customized to meet specific customer requirements, while complying with current fire safety regulations.

In the field of irrigation, Lowara produces pumps for agriculture, garden, and park irrigation. Even in the presence of large amounts of sand, the stainless steel pumps for deep wells and artesian wells remain consistently intact and efficient. High-suction steel jet pumps are designed to function properly even at low temperatures.

For industrial use, Lowara is involved in processes such as water purification, water treatment, washing systems, and machine tool cooling, as well as more advanced industrial sectors such as petrochemicals, energy production, and steel mills. Lowara offers a complete range of standardized pumps in cast iron and laser-welded 316L stainless steel. The products available are designed for high flow rates and heads. Advanced variable speed systems also offer the possibility of remote control, ensuring reliability and high energy savings.

1.7 Products

Lowara provides a wide range of products categorized into families, including both standard and highly customized products, where the technical design tailored to the customer's specific needs. The product range is constantly expanding with new product lines to meet evolving market demands.

The extensive use of A304 and A316 stainless steels underscore the company's commitment to technological innovation. These materials make the products safer and more durable, while technologies like laser cutting and welding ensure precise shapes that remain unchanged over time, with designs that are both accurate and functional.

In this way, the company is able to offer durable, solid products that resist chemical aggression.

1.7.1 Surface pumps

These are single or multistage centrifugal pumps with axial suction, available in both horizontal and vertical configurations. Within the Lowara offering, these pumps represent the widest range. The series of surface pumps is used in various sectors, including: water supply, rainwater collection, industrial washing machines, irrigation, water purification and treatment, cooling and refrigeration, swimming pools, heat recovery, heating, ventilation and air conditioning, washing of metal parts and/or surface treatment, washing of fruits and vegetables in the packaging industry, and many other industrial applications.

The pumps are made with various combinations of materials and mechanical seals to meet the requirements for pumping potable water and/or aggressive liquid.

Figure 1.5: e-HM series

HM-HMS-HMZ	Horizontal multistage pumps in AISI 304 or AISI 316 stainless steel
CEA-CA	Horizontal single/dual-impeller pumps in AISI 304 or AISI 316 stainless steel
CO	Horizontal pumps with open impeller in AISI 316 steel
SP	Self-priming pumps with side channel
BG	Self-priming pumps
AG-JEC	Pumps for swimming pools
P-PAB-PSA	Peripheral pumps
FH	Close-coupled end suction cast-iron pumps
SH	Close-coupled end suction pumps in AISI 316 stainless steel
SV 2,4,8,16	Vertical multistage 2-pole pumps in AISI 304 stainless steel
SV 33,46,66,92	Vertical multistage 2-pole pumps in AISI 304 stainless steel
SVI	Immersible vertical pumps
TDB-TDV	Vertical multistage pumps

Table 1.1: Surface pumps products portfolio

1.7.2 Circulation pump

High-efficiency circulators for multiple applications, including heating systems, air conditioning, and hot water systems.

Figure 1.6: Ecocirc Bronze

TLC	Circulators for domestic systems with threaded connections
TLCB	Sanitary circulators
TLCH	Circulators for civil systems
TLCHB	Sanitary circulators for high flow rate/head
TLCSOL	Circulators for solar system
TLCK	Circulators for cooling and geothermal systems
FLC-FLCT	Circulators for civil systems
EFLC-EFLCT	Variable speed circulators for civil systems
EA+(Ecocirc+Auto)	High-efficiency variable speed circulators
EV+(Ecocirc+Vario)	High-efficiency variable speed circulators
EB (V) (Ecocirc Bronze)	High-efficiency electronic circulators for hot water recirculation.
FC-FCT	Single and twin inline single-block in cast iron

Table 1.2: Circulation pump products portfolio

1.7.3 Submersible dewatering and sewage pumps

The range of Lowara submersible pumps has a wide variety of applications: from draining basements to transferring industrial liquids; from emptying pits, septic tanks, and drainage tanks to pumping wastewater.

Figure 1.7: DOC series

DOC	Submersible pumps for clear or dirty water
DIWA	Submersible pumps for clear or slightly dirty water
DN	Submersible pumps for clear or slightly dirty water
DOMO	Submersible pumps for wastewater
DL	Submersible pumps for wastewater
GLS	Submersible pumps for wastewater
GLV	Submersible pumps for wastewater
MINIBOX	Prefabricated lifting stations for clear water
MIDIBOX	Prefabricated lifting stations for clear or grey water
SINGLEBOX PLUS	Prefabricated lifting stations for wastewater
DOUBLEBOX PLUS	Prefabricated lifting stations for wastewater
MAXIBOX PLUS	Prefabricated tanks for lifting stations for wastewater
DEPURBOX	Treatment plants for domestic wastewater

Table 1.3: Submersible dewatering and sewage pumps products portfolio

1.7.4 Submersible pumps

The range of Lowara submersible pumps includes products suitable for deep wells with diameters ranging from 4" to 12". Lowara also offers installation accessories such as cooling and pressure jackets used for water supply from tanks, wells, reservoirs, and waterways, as well as for pressurization, irrigation, rainwater harvesting, and firefighting.

Figure 1.8: SCUBA series

SCUBA	Submersible single pumps -block pumps for 5" well
GS 4"	Submersible pumps for 4" well
Z-ZN 6"	Submersible pumps for 6" well
Z-ZR 8"	Submersible pumps for 8" well
Z 10" – 12"	Submersible pumps for 10"-12" well
4OS/C	Submersible motors for 4" well
MOTORI L4C	Submersible motors for 4" well
MOTORI L6C	Submersible motors for 6" well
MOTORI L6W/A	Submersible motors for 6" well
MOTORI L8WC	Submersible motors for 8" well
MOTORI L10W	Submersible motors for 10" well
MOTORI L12W	Submersible motors for 12" well

Table 1.4: Submersible pumps products portfolio

1.7.5 Pressure boosting sets for residential and commercial buildings

Wide range featuring 2, 3, or 4 pumps with control via pressure switches or pressure transducers, available in fixed or variable speed configurations. The Lowara range of pressure boosting systems has been designed for water supply to users with varying and intermittent needs, utilizing centrifugal pumps controlled by an electrical control panel.

Figure 1.9: GS series booster sets

GRUPPOSFERA	Single-phase pressure sets
BLOCK	Single-phase pressure sets
GENYO SYSTEM	Single-phase pressure sets
GXS20	Two pumps single-phase pressure sets
GMD20	Two pumps three-phase pressure sets
GTKS	Two pumps three-phase pressure sets, single-phase supply
GHV	Two pumps three-phase pressure sets, single-phase or three-phase supply
GS	Three-phase lifting sets
GHVR	Three-phase lifting sets
GV	Three-phase lifting sets

Table 1.5: Pressure boosting sets for residential and commercial buildings products portfolio

1.7.6 Control panels

Single-phase electronic control panels for the management of 1 or 2 pumps within various fixed-speed systems. Capable of handling over 50 different types of applications for pressure control or wastewater treatment. Ideal for use in various wastewater treatment applications, it can control up to 2 pumps (booster sets), and in the event of a control panel failure, the pumps continue to operate.

Figure 1.10: Q series

QSM – QPC – QPCS – QSC – QSCS	Single-phase control panels for submersible pumps
QM – QTD – Q3A – Q3D – Q3Y – Q3I – Q3SF	Control panels for surface and submersible pumps
QDR – QDR2 – QDRM – QDRMC – QDRM2 – QDRMC2 – QGMC – QYR – QYR2 – QXR20	Control panels for submersible pumps for drainage
QCL5 – QCL10 – QCLP10 – KSL – DPF – VR – SCA3 – KIT RILS20	Auxiliary control panels and accessories

Table 1.6: Control Panels products portfolio

1.7.7 Accessories

The accessories are paired with the range of pumps described, offering a wide variety of accessories including: pressure switches, pressure gauges, 5-way fittings, flexible hoses, Genyo, float switches, flow switches, check valves, water softeners, filters, and dosing pumps. Devices like GENYO and HYDROVAR are intelligent control and protection systems that automatically adjust the speed, start, and stop of the pump based on the actual water demand, preventing pressure fluctuations during continuous operation of the workstatio n.

In particular, the HYDROVAR system (Figure 1.9) provides the ability to control multiple pumps simultaneously, and due to its modularity, it is also suitable for applications with limited needs. HYDROVAR can be easily and quickly mounted on any new pumping system or retrofitted to existing pumps thanks to its 'clip and play' mounting brackets.

Figure 1.11: HYDROVAR and pump application

HVW	Pumps with Hydrovar® water cooled
HV 2.015 – 4.110	Hydrovar® 1,5 – 11 kW
HV 4.150 – 4.220	Hydrovar® 15 – 22 kW
HV 3.30 – 3.37 – 3.45 – wall mounted	Wall mounted Hydrovar® 30 – 45 kW
AQUONTROLLER	230 VAC drive for sigle-phase motors
TKS	Teknspeed pumps
SVH	Vertical multi-stage pumps with Hydrovar®

Table 1.7: Accessories products portfolio

1.7.8 Smart Pumps

Smart Pumps are intelligent and stable pumps that operate with precision even at partial loads, preventing water hammer typically associated with fixed-speed pumps (without drives). What sets them apart is the precise speed control during startup and operation, which helps reduce wear and mechanical stress. These pumps are used in water supply systems, residential buildings, air conditioning, water treatment plants, and industrial installations.

The Lowara Smart Pump combines three essential elements to ensure exceptional reliability, optimal savings, and a quick return on investment. (Water & Wastewater Products & Services | Xylem US, n.d.)

Figure 1.12: SMB variable speed pressure sets

Figure 1.12A: HME series, SVE series, LNE series

1.8 Lean Journey

To address the new market demands for a greater variety in the product mix, higher production volumes, and increasingly shorter delivery times, Lowara began its Lean transformation in 2001 when it was still part of ITT Corporation. During this process, the company transitioned from an organization based on traditional push production logic to the adoption of pull logic and Just In Time (JIT) principles.

The drivers of change were:

- The need to respond to customer demands for increasingly shorter lead times
- The need to provide highly customized pump models in small quantities (batch size of 1)
- The need to reduce costs to maintain competitiveness and profitability
- Pressure from the parent company for effective capital management (high inventory turnover rates)

To this end, a program called Value Based Six Sigma was launched, focused on reducing waste and process variability, centred on continuous improvement and following these five principles:

Value Based Management: identifying what contributes to creating value for the business and defining the key strategic and operational elements (evaluation of strategic positioning, selection and allocation of resources).

Leadership: This is the glue of the entire initiative (developing leadership capabilities, enhancing team effectiveness, and better utilizing each individual's skills).

Value-Based Product Development (VBPD): VBPD is based on the following principle: reaching the market quickly with highly differentiated products and superior features significantly increases sales and profits. It uses the Stage-Gate model (Cooper, 1988), focusing on customer requirements (VOC – Voice of Customers).

Six Sigma Problem Solving: The Six Sigma philosophy is based on a deep understanding of customer needs, a systematic use of facts and data, and statistical analysis to redefine business processes following the DMAIC approach.

Lean Production: Lean production is based on creating flow conditions for materials and information at all stages of the production process (production planning, kaizen, and bottleneck elimination, supply chain management, and lean flow production). Roles such as Lean Belt and Lean Master were introduced, and in the following years, the company invested in training the entire workforce through kaizen courses and events, as Lowara was and still is aware of the importance of engaging its people.

1.9 Conclusions

This chapter discusses Xylem Inc. and Lowara S.R.L. in very descriptive terms with respect not only to their supremacy in water technology but also in their stronghold in the global water domain, since their commitment to sustainable water solutions.

It provides context for Lowara's challenges such as operational efficiency and variability in service in response to what the market needs.

The chapter emphasizes the importance of having their operations in line with lean principles so as to sustain a competitive edge.

Chapter 2

Lean thinking e Toyota Production System

This chapter explores the Lean theory and the Toyota Production System (TPS), both of which are fundamental pillars in the creation of the production system developed by Xylem, known as the Xylem Production System (XPS).

2.1 Introduction to Lean Thinking and Toyota Production System

Lean Thinking and the Toyota Production System (TPS) are fundamental approaches to operational efficiency and business management. These concepts were developed to address the challenges of an increasingly competitive and dynamic world, where companies must adapt quickly to changing customer demands and market fluctuations. Lean Thinking and TPS provide tools and philosophies that enable organizations to achieve significant improvements in quality, productivity, and customer satisfaction.

At the core of Lean Thinking is the elimination of waste, a principle grounded in the focus on customer value. This approach urges companies to identify and eliminate any activity, process, or resource that does not add value to the product or service.
Waste can take various forms, such as excess inventory, waiting times, unnecessary movements, or overproduction. Lean Thinking encourages businesses to look beyond visible operations and critically examine every aspect of their production process, aiming to create efficient and unobstructed workflows.

The Toyota Production System, developed by the Japanese automotive company Toyota, is regarded as the origin of lean thinking. This system is based on a philosophy that extends beyond simple production, aiming to create an environment where every employee is involved in continuous improvement and problem-solving.

In the "Toyota Temple" context (Figure 2.1), the principles of the TPS represent the foundational pillars that support the structure.

The first pillar, *elimination of waste* (Muda), is central to the TPS philosophy. Waste elimination is essential for achieving efficiency and productivity. TPS principles and techniques, such as continuous flow, the pull system (Just-in-Time), and Kaizen (continuous improvement), all focus on reducing or eliminating waste in production processes or services.

The second pillar, *continuous flow* (Just-in-Time), focus on eliminating unnecessary inventory and producing only when needed. This principle is closely linked to waste elimination, particularly excessive inventory, and, together with waste reduction, creates a leaner and more responsive production environment.

The third pillar, *Kaizen* (continuous improvement), is rooted on the concept that improvement is an ongoing process involving all levels of the organization. Every team member participates in identifying and solving problems, reducing waste, and optimizing processes, contributing to overall efficiency and quality.

The fourth pillar, *Jidoka* (automation with a human touch), and Poka-Yoke (error-proofing) are principles related to process quality and defect prevention. Jidoka allows machines to autonomously detect issues and stop production, thereby preventing defects. Poka-Yoke is a system designed to prevent human errors, reducing the chance of defects. Both principles ensure the production of high-quality products.

Finally, the *standardization of processes* pillar is essential to all the other TPS principles. The use of standardized procedures ensures consistent execution of processes and establish improvements as new standards, guaranteeing the sustainability of gains achieved through Kaizen.

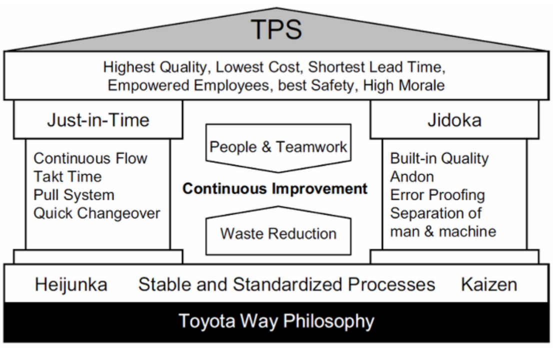

Figure 2.1: The Toyota Temple

Each of these pillars is considered vital for the stability and success of the "Toyota Temple." The use of this metaphor emphasizes that the TPS is not a set of practices to be followed mechanically but a management philosophy deeply rooted in Toyota's corporate values. It represents the idea that Toyota's ongoing success and its leadership in the global automotive industry stem from its constant adherence to the principles and values of the "Toyota Temple." This concept has also inspired other organizations to seek to adopt and adapt TPS principles in their production and management processes.

2.2 Fundamental Principles of the Lean Thinking

Lean Thinking originated within Toyota with the Toyota Production System (TPS), while the term "lean" was coined by John Krafcik in 1988 in the article *"Triumph of the Lean Production System* (Krafcik, 1988). In this article, Krafcik explained how to create more value for customers using fewer resources. He also aimed to demonstrate that corporate culture, rather than level of automation, was correlated with plant performance. Companies that operate under the lean ideology can produce a wide range of models while maintaining high levels of quality and productivity.

The Toyota Production System is not merely a production system but a philosophy that extendes beyond the factory. Shigeo Shingo, a collaborator of Taiichi Ohno, the father of this production system implemented at Toyota, describes it as follows:

"What is the Toyota Production System?
80% of the people you ask will say it is a system based on kanban cards, another 15% will claim that it is a production system, and only 5% will grasp the true essence of the question and answer that it is a system for the elimination of waste."

The process of lean was thoroughly described in the book *The Machine That Changed the World* (Womack et al, 1990). In a subsequent volume, *Lean Thinking* (Womack et al, 1996), Womack and Jones went deeper into these lean principles even further, distilling five major principles (Figure 2.2):

Figure 2.2: The 5 Lean Principles

1. Identify Customer Value

   Identifying the value perceived by the customer and focusing on activities and processes that add value to the product or service offered is essential. The starting point of lean thinking is the concept of value, which can only be defined by the end customer and takes on meaning only when expressed in terms of a specific product capable of meeting the customer's needs at a particular price and at a given time. From the customers' perspective, value is the reason why producers exist.

2. Map the Value Stream

   The second step in lean thinking is identifying the value stream for each product or product family. The value stream consists of all the actions required to move a given product through problem-solving, information management, and the physical transformation of raw materials into a finished product in the customer's hands. This phase almost always reveals enormous amounts of waste (muda).

   In mapping the value stream, three types of activities are identified:

   - Activities that create value
   - Activities that do not create value but, given current technologies and production systems, are unavoidable (Type 1 muda).
   - Activities that do not create value and can be eliminated immediately (Type 2 muda).

Creating lean enterprises requires a way of thinking about intercompany relationships based on transparency regarding the steps taken along the value stream, which also impacts the relationship with suppliers.

3. Create Flow

   After precisely defining the value and completely reconstructing the value stream for a product family, eliminating all unnecessary activities, the next step is to ensure that the remaining value-creating activities flow seamlessly. The enemies of flow are all forms of waste (muda), including waiting due to queues and batches, inventory, interruptions caused by lack of information, inefficiencies from suppliers, and rework. To enable the fast flow of the value stream, several specific techniques are employed, such as studying Takt Time, reducing batch sizes, implementing One-Piece Flow, creating flow-based layouts, balancing stages, levelling, and scheduling based on the pacemaker process.

4. Establish Pull

   This means ensuring that the value stream is "pulled" by the customer. Value-creating activities must be triggered by the customer themselves, otherwise, a cost would be generated without producing value, leading to waste. In this case, lean production responds with specific pull systems: kanban, supermarkets, and controlled inventory management of products.

5. Seek Perfection

   The first four principles interact with each other in a virtuous circle, because making the value flow faster means identifying hidden waste (muda) in the value stream. The more the flow is pulled, the more obstacles to the flow of value are highlighted and can be removed. Additionally, since the elimination of waste sometimes requires new technological processes and new product concepts, these are often surprisingly simple and already available.

   The process of improving flow, thus reducing waste, and focusing on customer value should never end. Perfection is not a static concept but a dynamic one, as customer value changes over time, and this ongoing tension serves as the benchmark to keep a systematic improvement process alive and active. The ultimate goal is the complete elimination of waste so that all activities create value for the end customer.

2.2 Toyota way

The "Toyota Way" is a corporate philosophy that reflects the principles and practices guiding the Japanese automobile company Toyota. It serves as a guide for management and how Toyota addresses organizational and production challenges. The Toyota Way was developed as an expansion of the Toyota Production System (TPS) principles and focuses not only on production but also on how the company manages its operations in general. This philosophy was widely spread also thanks in this 2003 book *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer* (Liker, 2003).

The Toyota Way is based on 14 core principles, which can be divided into four main categories:

1. Long-term philosophy: This category reflects Toyota's long-term approach and includes the following principles:

- *Principle 1*: "Base decisions on a long-term vision, even at the expense of short-term financial gains."
- *Principle 2*: "Create a corporate philosophy of sustainable development that involves all stakeholders."

2. Right processes: This category focuses on the effectiveness of organizational and production processes:

- *Principle 3: "Use workflow to surface problems."*
- *Principle 4: "Make processes visible to reveal issues."*
- *Principle 5: "Use only tested and standardized processes."*
- *Principle 6: "Encourage evolved thinking to continuously improve processes."*

3. People and partners: This category emphasizes how people are involved and developed within the organization:

- *Principle 7: "Build a learning culture that fosters the development of people."*
- *Principle 8: "Develop leaders who fully understand the work, perform it, and teach it."*
- *Principle 9: "Create a network of partners that demonstrate respect for Toyota's philosophy."*

4. Solutions to continue growing: This category focuses on the company's continuous growth and adaptation:

- *Principle 10: "Develop a growth objective and growth capabilities."*
- *Principle 11: "Make growth and development a daily objective."*
- *Principle 12: "Innovate and shape the future."*

The Toyota Way emphasizes the importance of a scientific approach to problem-solving, process standardization, employee involvement, growth, and continuous improvement. These principles have contributed to Toyota's success and reputation as a leading company in the automotive industry and have become a reference point for many other organizations seeking to implement similar principles to improve their efficiency and corporate culture.

2.3 Wastes

The focus of Lean is to provide value to the customer through the reduction of waste. These are activities that consume time and resources without adding value to the end customer and can be divided into three categories, closely related, known as the 3Ms: MUDA (waste), MURI (overburden), and MURA (variability) (Figure 2.3).

Figure 2.3: Muri, Mura and Muda

The seven wastes, or muda, were listed by Taiichi Ohno as follows (Ohno, 1988):

1. Defects (in products)
2. Overproduction of goods. When production is managed through a push system, to maximize the use of equipment, reduce setup times, and produce large batches to lower unit costs, overproduction occurs. This in turn causes all the other wastes listed below (Rother et al, 1999).
3. Extra-processing
4. Motion (of people)
5. Transportation (of goods)

6. Waiting times (employees waiting for process equipment to finish or for upstream activities to complete).
7. Inventory of goods waiting for further processing or usage. Inventory results from overproduction and differing production rhythms between sequential processes. Specifically, the presence of inventory prevents the identification of problems and wastes in the system, as they are hidden by the inventory.

The ones presented before are the original wastes identified by the Toyota Production System, but with time another kind of waste came out as crucial to identify and eliminate:

8. Unused Talent, the waste of human potential. Non-utilized talent occurs when organizations separate the role of management from employess, not engaging the frontline's workers knowledge and expertise, making it more difficult to improve processes. (Skhmot, 2017)

In addition to waste defined as muda, there are two other forms of waste: *mura* and *muri*.

MURA refers to irregularities in the flow and/or workload. Variability is detrimental because it disrupts the proper sizing of the system, making it difficult to implement. As a result, there will be times when resources appear oversized and other times when their utilization is extremely low. The root cause of this waste is the failure to level demand.

MURI, on the other hand, refers to overburdening people or resources. This happens when productivity is increased without properly organizing the work. This leads to employee dissatisfaction and a lack of attention to tasks that become repetitive. Possible consequences include increased risks of accidents and occupational diseases, which in turn lead to absenteeism. Similarly, excessive use of machinery increases the need for maintenance, resulting in production downtime. Ultimately, overuse of equipment reduces its lifespan, leading to significant additional costs.

To eliminate muri, standardization can be applied by defining work stages and flows, or the pull system can be introduced by reducing batch sizes and balancing the production flow.

2.4 Tools for continuous improvement

The application of continuous improvement in an organization requires the use of various tools and techniques to identify, analyze, and solve problems, as well as to monitor and measure progress over time. Here are some common tools used in the context of continuous improvement:

2.4.1 Ishikawa Diagram

The Ishikawa Diagram (Figure 2.4), also known as the Cause-and-Effect Diagram or Fishbone Diagram, is a fundamental tool for cause analysis in the context of Lean Thinking and continuous improvement. Created by Japanese professor Kaoru Ishikawa, this diagram provides a visual framework to identify and understand the causes of a problem or inefficiency in a process or system. Its shape resembles the backbone of a fish, with lateral "bones" representing the general categories of causes that may contribute to the problem. This tool is widely used for brainstorming and analysis sessions, involving work teams in the search for effective solutions. The Ishikawa Diagram helps highlight the relationships between causes and the desired effect, allowing the team to focus on the main causes to address the problem in a targeted way. It is a valuable tool for continuous improvement, problem-solving, and fostering a company culture focused on quality and efficiency.

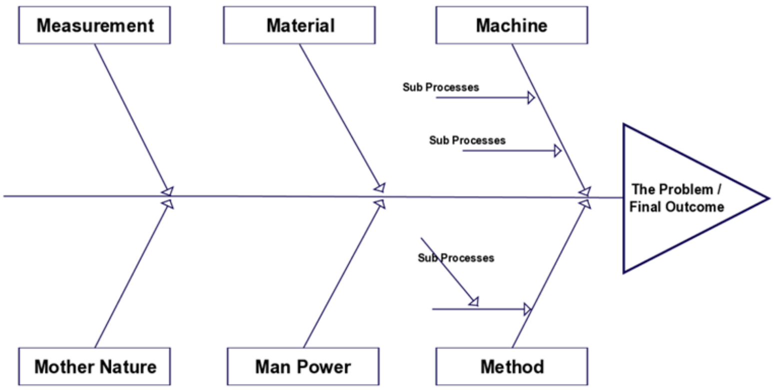

Figure 2.4: Ishikawa Diagram

2.4.2 A3-X e A3-T

The A3-X (Figure 2.5) is a matrix that links strategy, tactics (how to implement the strategy), indicators, objectives to be achieved, and the people involved in the projects.

It is completed as follows (Jackson, 2006):

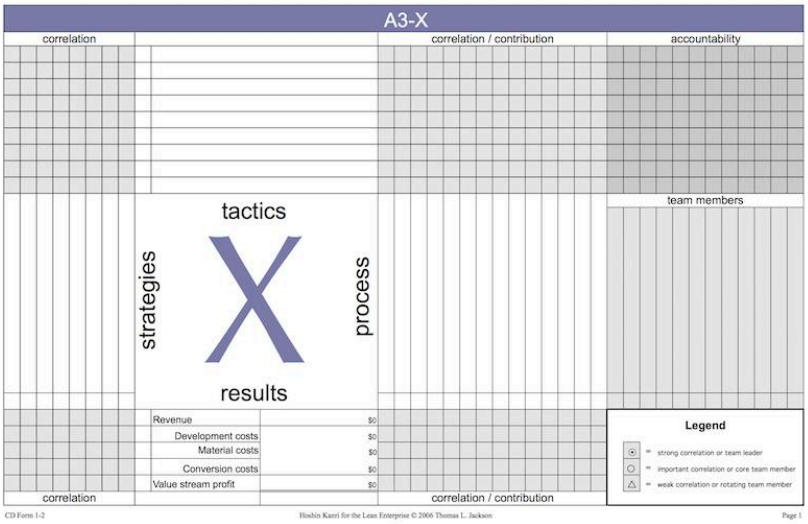

Figure 2.5: A3-X example

1. Begin by filling in the left-hand side concerning the strategies, which are high priority for the current year and for success in the next 2 or 3 years.
2. From the strategy, tactics emerge, which are listed at the top of the matrix and represent improvement projects and initiatives for the current year.
3. The improvement projects require performance measures of the process, which are written on the right side of the X. Indicators are established to monitor progress.
4. The A3-X shows, in the upper right quadrant, the relationships between individuals, teams, departments, and suppliers.
5. In the Team Members section, all the people cooperating to achieve the targets are listed.
6. Below the X, the desired outcomes are reported, which are measured in both economic and non-economic terms.
7. The correlation matrices within the X-Matrix represent the interrelationships between the critical factors within the business strategy.

Moreover, the X-matrix is designed to link multiple A3-Ts (there will be one for each project), explore their interdependencies, and relate them all to the outcomes. The A3-T appears as "tactics" within the A3-X and is a structured approach that describes a problem and the story of its resolution. It has no single inventor, as it was developed within Toyota's Quality Circle, and it owes its name to the size (420x297mm) of the paper used to create it. It serves as a collaborative problem-solving method that promotes a logical and objective way of thinking based on:

1 Data

2 Objectives and results
3 Synthesis - "If you can’t say it with one page, you’re not concise enough" (Ohno T.)
4 Graphic representation: the topic addressed should be understood at first glance
5 Alignment: The A3 is also used as a reporting tool to update management
6 Consistency and an overall perspective.

The A3 helps foster a culture of continuous improvement and can be used by anyone who wants to become a problem solver. It is built on the PDCA logic, meaning it follows a sequence of steps where one phase must be completed before moving to the next. This ensures that conclusions are not rushed without fully analyzing all implications.

The A3 structure (Figure 2.6) can be easily explained either the following 8 sequential points, that must be fulfilled and followed to successfully analyse and solve the problem.
The points are:

1) Clarify the problem (*problem statement*)

   In this this stage you need to identify the problem by answering to the 5W1H[1]:
   - *Who*: Who is affected by the problem? Who are the stakeholders?
   - *What*: What is the issue? What is not the issue?
   - *Where*: Where is the problem occurring? Where is it not occurring?
   - *When*: When does the problem happen? When does it not happen?
   - *Why*: Why is this a problem? Why might it have occurred?
   - *How*: How does the problem manifest? How can it be solved?

2) Break down the problem

   When the problem is well identified in all its shades, what needs to be done is breaking down the problem, that means identifying the main perturbances that led to a deeper analysis for the resolution of it. Here background and “first-impact” effects need to be stated in order to set the baseline for further analysis.

3) Set the goal

   After the main points related to the problem have been explained, the goal of the analysis needs to be defined.

[1] It is a structured approach to problem-solving that aims to provide a clear understanding of a particular issue by exploring the issues from all the point of views. The acronym stands for Who, What, Where, When, Why, and How.

At this stage the target state needs to be clear and coherent with what has been stated before. This can be affected by multiple factors given by the surrounding environment, leaving space to shape a tailored objective.

4) Analyse root causes

This is the most crucial part because the goal can be reached only if all the root causes are identified, otherwise there could be unexpected outputs due to omitted variables.

To categorize the causes that can be seen at first sight, the Ishikawa diagram can be one of the tools that helps the work.

After the method has been applied and none of the causes are left with unknown category, a deeper analysis needs to be done on each of them.

The method used to do that is the 5 Whys: by repeatedly asking "why" to each answer to causes, it is possible to reach the stage in which there is no more answer, meaning that the root cause has been identified.

5) Develop countermeasures

When all the root causes have been identified, countermeasures need to be written down in order to eliminate their impact, or at least bring them to a minimum.

While doing so, each countermeasure needs to be classified inside of a Benefit/Effort matrix, so that it ca be easier to understand the timeline and the resources to put them in action.

6) Implement and verify the effectiveness of corrective actions

At this point, the previously defined countermeasures now need to be implemented in order to have feedback on the effectiveness of the corrective actions.

A good way to do it is to create a GANTT chart[2], and by doing that you can have a clear visualization of the countermeasure's implementation, which makes it easier to see and evaluate effectiveness.

7) Evaluate the process and results

This is another crucial part in the process, that is because now effectiveness needs to be monitored for a certain period of time (usually around three months) so that it is possible

[2] A Gantt chart is a project management tool that illustrates work completed over a period in relation to the time planned for the work. It typically includes two sections: the left side outlines a list of tasks, while the right side has a timeline with schedule bars that visualize work. (Meardon, n.d.)

the evaluate if the corrective actions are having the expected results and if the new processes are being properly applied.

8) <u>Standardize the success and learn</u>

If in the previous point the feedback analysis had a positive output, then the already put in place actions now need to be standardized. By standardizing what has been proven to have positive effects, it is possible to be sure that there will be a more robust and solid process. In this late phase it is also time to look back at the previous steps, taking notes of what went wrong and what was a success, to learn from experience.

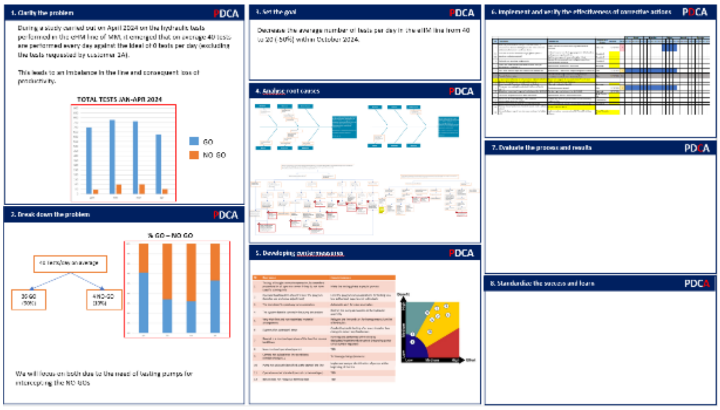

Figure 2.6: A3-T example

2.4.3 Value Stream Mapping

Value Stream Mapping (VSM) (Figure 2.7) is a powerful tool used in Lean Thinking to analyze and optimize production processes and workflows. It is the first and essential lean tool because:

1 It allows the visualization of the flow, where individual activities are located.

2 It helps to identify waste, locate its source, and identify improvement opportunities.

3 It shows the connection between the material flow and the information flow.

4 It links lean techniques and concepts, allowing them to be used coherently together.

5 It provides a common language for discussing the production process.

6 It is a qualitative tool that describes in detail how the process occurs (Rother et al, 1999). This tool, with paper and pencil, helps to understand the flow of materials (from raw

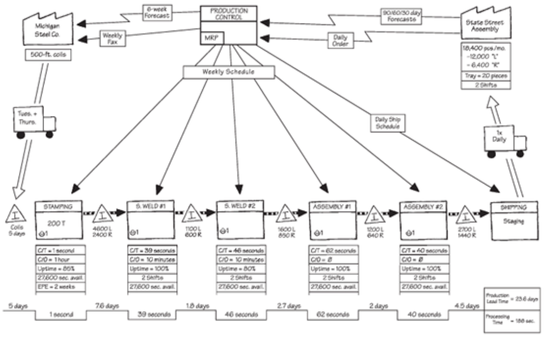

Figure 2.7: Value Stream Map Example

material to finished product, i.e., from supplier to customer) and information (in reverse, from customer to supplier) as a product moves through its value stream. When talking about VSM (Figure 2.5), it refers to following the production path of a product from customer to supplier, making it necessary to define what is in scope and out of scope for the process under analysis.

Once the current state mapping is completed, a "timeline" will be drawn, which shows how much "value-added" time is contained within the lead time. One of the objectives of the future state (VSM TO BE) will be to reduce non-value-added time in favor of value-added time (to improve the response time to the customer).

In summary, this tool allows you to see the value, differentiate it from waste, and by designing a "future state" plan where and how to eliminate waste.

2.4.4 Spaghetti Chart

It is a visual tool used in the context of Lean Thinking to analyze and optimize workflow within a process (Figure 2.8). This diagram is named after its resemblance to a tangle of spaghetti and graphically represents the paths followed by people or objects while completing a series of activities.

It helps identify unnecessary movements, delays, overlaps, and inefficiencies within a process, clearly visualizing where time and resource waste occurs. Once these issues are identified, targeted improvements can be made to minimize movement and optimize workflows.

It is a useful tool for promoting the design of more efficient layouts, improving logistics, and increasing overall process efficiency, thus contributing to leaner and higher-quality production or service performance. This mapping highlights all the movements (muda) performed, all the crossings made (resulting from a non-optimal layout), the meters travelled during the production cycle, and numerous other useful pieces of information (Hessing, 2022)

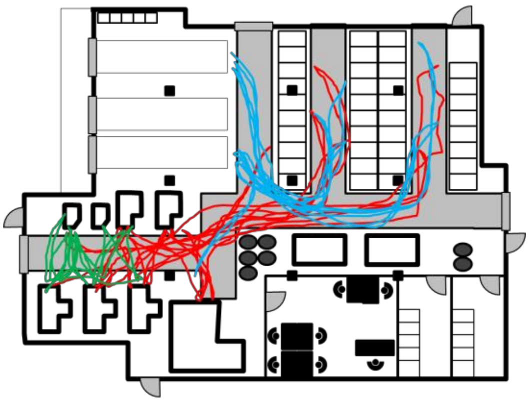

Figure 2.8: Spaghetti Chart Example

2.4.5 5S

The 5S is a systematic and permanent method, applicable in both production and office environments, that allows for achieving excellence by improving the workplace through order, organization, and cleanliness. Maintaining these conditions makes it easier to highlight and identify problems.

The 5S refers to five Japanese terms that indicate the stages of the methodology (Figure 2.9):

1 **Seiri** – *Sort*. Eliminate anything unnecessary from the workstation. This means removing all non-essential equipment/tools from the workbench that are not required for the ongoing production activity.

2 **Seiton** – *Straighten*. Efficiently organize the tools, equipment, and materials that were deemed essential in the first phase. The goal is to reduce the time spent searching for materials/tools and make it easy to use and store objects.

3 **Seiso** – *Shine*. Which means ensuring the order and cleanliness created. Make sure that floors and machinery are clean, as well as the entire company. In this way, anomalies and anything out of place immediately stand out.

4 **Seiketsu** – *Standardize*. Standardization is the method for maintaining the order and cleanliness created in the first 3S and striving for improvement by continuously repeating the phases: Seiri, Seiton, Seiso.

5 **Shitsuke** – *Sustain* over time. Discipline and rigor are fundamental to ensure that the application of correct procedures becomes a habit over time (Michalska, Danuta, 2007).

Figure 2.9: 5S

2.4.6 5 Whys

The "5 Whys" is a problem analysis technique used to get to the root of a situation or problem by going beyond the surface to uncover underlying causes (Figure 2.10). This technique involves repeatedly asking the question "Why?" to delve deeper into an issue and identify its root causes. The goal is to move past immediate answers and uncover hidden causes that may contribute to the problem.

The "5 Whys" technique is often used within Lean Thinking and Six Sigma to solve problems and improve processes. It promotes a deep understanding of problems rather than a simple superficial fix. The sequence of "Why?" questions can be adapted based on the complexity of the problem and the context. This technique encourages critical thinking and the discovery of the core causes of an issue, enabling the development of targeted solutions to prevent recurrence.

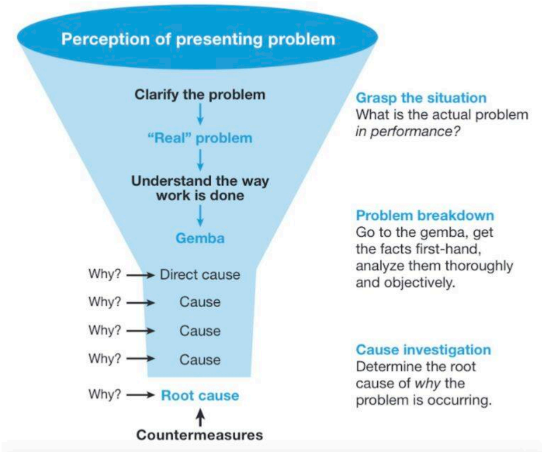

Figure 2.10: 5 Whys Funnel

In short, the "5 Whys" is an effective tool for problem-solving and promoting continuous improvement within an organization.

2.4.7 PDCA

The Deming Cycle, also known as PDCA (Plan-Do-Check-Act) (Figure 2.11), is a widely used quality management model in the context of continuous improvement and Lean Thinking. This cycle, developed by William Edwards Deming, provides a clear structure for managing processes and achieving consistent improvements.

The PDCA cycle is divided into four stages:

1. **Planning (Plan):** In this phase, goals, problems, or improvement opportunities are identified. Necessary actions to achieve the objectives are planned, and measurement metrics are defined to assess success. This phase is crucial for establishing a solid strategy.

2. **Execution (Do):** Here, the actions planned in the previous phase are put into practice. Changes in processes are implemented, or necessary tests are carried out to see if the solutions actually work.

3. **Checking (Check):** This phase involves evaluating the results obtained against the established objectives. Data is collected and analyzed to determine if the actions taken were successful or if further improvements are needed.

4. **Acting (Act):** Based on the results of the check phase, corrective actions are decided. If the results are positive, the new processes are standardized. If there are still issues, the cycle begins again to plan and implement further improvements (Isniah, et al. 2020).

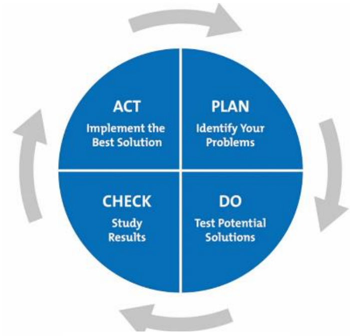

Figure 2.11 PDCA Cycle

The PDCA is a cyclical approach, meaning that the process continues iteratively. This constant cycle of planning, execution, checking, and acting enables organizations to adapt to change, address problems systematically, and pursue continuous improvement. The PDCA is a fundamental tool for quality management and for promoting a culture of learning and adaptation within organizations.

2.4.8 DMAIC

The DMAIC cycle follows an empirical approach that is made of five stages (Slack et al., 2022):

1 Define:

The purpose of problem definition is to understand the requirements necessary to carry out the improvement process. In this first phase, improvement objectives are set, which must be shared by the team. To set effective targets, one should think of the SMART acronym, which stands for:

- *Specific*: define a specific area for improvement
- *Measurable*: quantify or at least identify an indicator to measure progress
- *Assignable*: specify "who does what"
- *Realistic*: define what result can realistically be achieved with the available resources
- *Time-related*: set a time horizon within which the result will be achieved.

More than the goal itself, its combination with the Action Plan is crucial (Doran, 1981).

2 Measure:

The second phase, measurement, is used to collect data on the current state and is essential because the Six Sigma approach emphasizes empirical data. The purpose of this phase is to validate the problem, ensuring that it is worth solving, and to establish a baseline database.

3 Analyze:

The analysis phase is meant to understand what isn't working within the current process and to develop hypotheses about the root causes of the problem. For root cause analysis, various tools can be used, such as the Ishikawa diagram or the 5 Whys method.

4 Improve:

This is the implementation phase, where the most profound causes of the problems are addressed by testing the most promising solutions, which are then formalized with the measurement of the results.

5 Control:

The final phase, after which the cycle restarts, involves monitoring the process to verify that the improved performance is sustained over time. Afterward, the cycle starts again with the Define phase, where the criticalities preventing further improvement are identified.

By adopting a philosophy of continuous and incremental improvement, the cycle is designed to restart and never stop.

2.5 Challenges

Despite the numerous successes and advantages associated with the adoption of Lean Thinking and the Toyota Production System (TPS), it is important to acknowledge that there are challenges and criticisms to face when attempting to implement these concepts in an organization.

One of the main challenges is the cultural shift required. Transitioning from a traditional production model to a lean one demands a radical change in mindset and behaviors. Engaging and gaining the commitment of all levels within the organization can be difficult, especially in companies with well-established hierarchical structures.

Along with the cultural shift, resistance to change can be a significant challenge. Employees may feel threatened by changes to their roles and responsibilities, slowing down the adoption of new practices. Clear communication and proper training can help address this resistance. While TPS can be adapted to various industries, every organization has its own unique needs and challenges. Finding the right balance between applying lean principles and adapting to specific realities can be complex and requires a deep understanding of business dynamics. Measuring the tangible results of TPS implementation can be difficult. The benefits may be long-term and can vary from one organization to another. Determining which key performance indicators (KPIs) are relevant and how to measure them accurately can be challenging.

A common criticism of Lean Thinking is that its excessive focus on efficiency may overlook other important aspects such as innovation, creativity, and the ability to respond to unforeseen changes. This could lead to a lack of flexibility in unexpected situations.

In some more complex industries or contexts, the direct application of TPS may not be sufficient or even appropriate. Situations where uncertainty is high or where high levels of customization are required may call for a different approach.

In conclusion, adopting these concepts requires a long-term commitment, strong leadership, and a deep understanding of organizational dynamics. Addressing challenges proactively and adapting the approach based on specific circumstances can help maximize the benefits of implementing these concepts.

2.6 Conclusions

The chapter introduced the theoretical underpinnings of lean thinking and Toyota Production System (TPS).

Waste elimination, value creation, and continuous improvement are explained as the jacketing principles for operational excellence.

Key lean tools such as Value Stream Mapping, 5S, and PDCA are introduced, along with a discussion on how they are applicable in identifying inefficiencies and driving process improvements.

The chapter also looks at the hurdles which organizations go through while implementing lean methodologies.

Chapter 3

Xylem Production System (XPS)

In the previous chapter, lean concepts and the structure of production systems, such as the Toyota Production System, were explored. In this chapter, the Xylem Production System (XPS), the production system developed by Xylem in 2015, will be examined. XPS was designed to standardize the production process within the organization. A key element of the system is the focus on continuous improvement and the lean philosophy, which permeates the entire Xylem organization.

The elements of the Xylem Production System will be analyzed, including the lean principles, such as continuous flow, waste reduction, visual management, and employee engagement. It will be illustrated how these elements integrate into Xylem's production system to promote operational efficiency, reduce costs, and maximize customer value.
Additionally, specific tools and practices used in XPS, such as Kanban, 5S, and Kaizen, will be analyzed, as well as how they are applied within the organization to promote continuous improvement at all levels.

This detailed analysis of XPS will provide an in-depth understanding of how Xylem implements the lean philosophy and promotes efficiency and quality within its production processes.

3.1 Xylem Production System

As Xylem is a multinational company with multiple locations around the world, it became necessary to develop a set of processes, methodologies, and work tools to ensure a uniform approach and a consistent corporate standard. This standard not only provides guidelines for business activities but also serves as a tool to measure the improvement of business performance year after year and to continuously improve.

XPS, an acronym for "Xylem Production System," is the model created by Xylem in 2015 that provides a common language among all the company's locations worldwide. This model allows the organization to operate as a single company, with the ultimate goal of increasing customer satisfaction.

The creation and application of this standard also provides an evaluation tool used to measure the improvement rate of a production site and to share best practices between different locations. Additionally, it helps set future expectations and define improvement goals.
In creating XPS, the company was inspired by the structure of production systems such as World Class Manufacturing and the Toyota Production System. However, these pillars were adapted to meet Xylem's specific needs and realities, thereby defining a structure based on the SQDIP model (Safety, Quality, Delivery, Inventory, Productivity). This model provides a comprehensive framework for performance improvement in all key aspects of Xylem's production process.

In summary, XPS represents a unified system that promotes efficiency, quality, and continuous improvement within Xylem, enabling the company to operate as a single global entity and consistently deliver an enhanced customer satisfaction experience.

3.1.1 The XPS Pillars – SEQDPI approach

The pillars of the Xylem Production System (XPS) were selected based on the identification of critical areas that have the greatest impact on business performance:

- **Safety**: This pillar focuses on ensuring a safe work environment for all employees and promoting safe practices and behaviors.

- **Engagement**: Engagement is crucial in order to work in an effective way, so in the last year Xylem decided to add also engagement as one of the pillars of its production system. It focuses on direct workers engagement in the company’s life.

- **Quality**: The quality pillar aims to ensure that Xylem's products and services meet or exceed customer expectations. It focuses on defect prevention, quality control, and process improvement.

- **Delivery**: This pillar is concerned with the efficiency and timeliness of deliveries to customers. The main objective is to reduce lead times and ensure on-time product delivery.

- **Productivity**: This pillar focuses on the efficiency of production operations, aiming to maximize resource utilization and minimize downtime.

- **Inventory**: The inventory pillar seeks to optimize stock management, reducing waste and maintaining adequate levels of raw materials and finished products.

Continuous Improvement forms the foundation of the pillars, as it is a key element in creating a standard and serves as an input that guides the company towards a lean approach aimed at increasing customer satisfaction. For this reason, Xylem considers it essential to measure the maturity level of Continuous Improvement. However, assessing Continuous Improvement alone does not provide a complete picture of a production site's maturity level.

It is also necessary to measure the maturity of all the pillars, and for this purpose, XPS is the tool used to standardize the evaluation of a site's maturity level. This type of assessment allows leaders to gauge the organization's progress in terms of the Lean Six Sigma perspective, identify strengths, weaknesses, and improvement opportunities.

3.1.2 Internal Audits

For each pillar, corporate audits are conducted following XPS guidelines to diagnose the current maturity level of the area under review. These audits are carried out annually and include a site audit by a local team (self-assessment) followed by a corporate-level audit (peer assessment). This approach allows sites to benchmark against other locations within the organization, leveraging the expertise of the corporate team, and to undertake improvement actions based on the findings of the audits.
XPS provides an essential foundation for creating a multi-year "Improvement Roadmap" for each site. The roadmap is mandatory for all Xylem sites and is developed for each pillar. This is crucial because the pillars represent the most critical impact areas that require continuous monitoring and the identification of any issues through corporate audits. The roadmap allows sites to address and close any gaps with optimally managed improvement actions, thanks to a structured pathway.

3.1.3 Company Performance

Esiste una forte correlazione tra le metriche primarie e i pilastri SQDIP. Un aumento della maturità di una particolare area aumenterà le prestazioni delle metriche interessate. Ad esempio, un'elevata maturità nella sicurezza aumenterà la probabilità di raggiungere e sostenere elevate prestazioni di sicurezza. L'elemento Continuous Improvement (CI) influisce sul modello generale in due aspetti principali: - - Produttività del lavoro Capacità di implementare il cambiamento/miglioramento nelle varie aree SQDIP La maturità CI è considerata fondamentale per gli altri pilastri funzionali. Come mostrato nella figura 3.5, ogni uno dei 13 elementi del CI ha un impatto elevato (H) o medio (M) sulla maggior parte dei pilastri, mentre le aree relative alla sicurezza, qualità, consegne e produttività (materiali) hanno un impatto diretto solo su un pilastro specifico (quello corrispondente alla propria area) e un impatto basso (L) sugli altri pilastri. Per quanto riguarda la leadership e la cultura, sono considerati elementi abilitanti (enablers) essenziali per instillare la cultura del miglioramento continuo in tutta l'azienda, avendo quindi un impatto diretto sui pilastri SQDIP.

3.2 Continuous Improvement

At the core of defining a standard, best practices, and improvements is Continuous Improvement (CI), which aims to challenge the status quo, engage employees in problem-solving, and apply lean principles daily to foster a proactive mindset and increase customer value. Since Continuous Improvement is the foundation of the XPS pillars and an integral part of productivity, Xylem aims to measure the CI maturity level at each site.

To diagnose the current state of maturity, a site audit (self-assessment) is conducted by a local team, which provides an overall score based on the average of the scores assigned to each of the 13 CI elements identified as essential for achieving goals. Scoring each element allows the identification of starting points for implementing improvements in order to reach a target or ideal score set at the corporate level.

At the corporate level, an "external" team from outside the site periodically conducts an audit (peer assessment) to verify the accuracy of the self-assessment performed by the local team and to check the progress of the improvements implemented based on actions recommended during the previous corporate audit. The peer assessment, combined with the expertise of the "external" corporate team, enables benchmarking against other Xylem sites, facilitating improvements and subsequently increasing the current state score.

3.2.1 Leadership

Leadership is the essential element for managing change, communication, and spreading the company culture. In this key element, the level of leadership commitment is defined through the use of change management techniques to support and guide improvement activities (Point

Kaizen, Kaizen, 5S, Lean, Standard Work, Six Sigma, and Change Management). The improvement strategy is developed and planned, including Lean implementation with clear objectives and KPIs.

The vision is to have management that leads by example, acts as a role model, and inspires the staff. Stability is ensured by leaders responsible for the site's performance (Operations and CI leaders), and therefore all positions must be incorporated into the organizational structure. Since Xylem is a multinational company, the organizational chart is quite complex, but typically each site has a hierarchical structure with a site leader at the top, to whom all others report.

Communication is a critical element for engaging all employees within a site. For example, the management of daily improvement (MDI) is usually structured around the site's primary metrics (Safety, Quality, Delivery, Inventory, Productivity), allowing quick understanding of how the cell/department/site is performing. Obeya rooms are used to provide visibility of site performance, strategy, and ongoing actions.

The *gemba*[3] principle is widely practiced. A Gemba walk refers to the personal observation of work where it is being done, with the original Japanese term "gembutsu" meaning "real thing" or "where the work is done." Gemba is a key principle of the Lean approach, with the aim to:

1 Bring leaders closer to employees and foster dialogue on improvement opportunities.
2 Help make decisions based on facts and data instead of assumptions and beliefs.
3 Collect data for Kaizen pre-work.

Gemba is not a daily parade of managers at visual boards but a thoughtful observation of the Process flow, Operators, and Materials. It creates an opportunity to coach others through active communication-based methods.

3.2.2 Culture

This element aims to promote a culture of continuous improvement: challenging the status quo, engaging employees to tackle problems, and applying lean principles every day to increase customer value. The vision is to embed CI (Continuous Improvement) into everyone's DNA, solving daily problems with a mindset focused on continuous improvement.

[3] The term *gemba* originates from Japan and means “the real place” or “the place where things happen.” Within Lean Management, Gemba refers to the workplace where value is created. (Pereira, 2024)

In a facility, a pilot cell, called the "Model Cell," is used as a reference to demonstrate a good understanding of basic CI standard tools (5S, A3 Problem Solving, Continuous Flow, Standard Work, Value Stream Map, Visual Management - SQDIPE Boards, Strategy Deployment) before implementing more advanced standards (Pull System, TPM, DMAIC, Quality Control & Process Variation, SMED).
Currently, there are two Model Cells at the Montecchio site: the Nava automatic press line (WCP) and the SCUBA assembly line. The WCP is a multi-product stamping line of great importance, as it provides most of the semi-finished products used in the most demanded finished product families by end customers. The SCUBA assembly area, on the other hand, is dedicated to the final assembly of components for the production of finished products ready for distribution to customers.

3.2.3 Voice of Customer

The Voice of the Customer is a valuable tool for improving processes and product quality. To this end, the site conducts quarterly surveys to assess customer satisfaction and treats every opportunity to interact with the customer as a chance to learn and improve. Customer complaints typically come through communication channels such as meetings, phone calls, factory tours, board meetings, product returns, warranties, visits to customer facilities, etc. The site has a documented method for collecting customer feedback, and there are activities based on this feedback, as well as evidence of implementation, leading to organizational improvements.

3.2.4 Strategy Deployment

Strategy Deployment is the process that cascades the strategy throughout the entire company, requiring a certain level of alignment both between and within entities. Priorities are defined, and a series of documents is used to ensure proper communication and follow-up.

The vision is to have actual delivery times identical to planned delivery times, thanks to the high level of predictability in machine output. Each year, the local management team meets to define the priorities and plan for the upcoming year.

3.2.5 5S

5S (Sort, Set in order, Shine, Standardize, Sustain) is a systematic step-by-step process aimed at eliminating waste that contributes to errors, defects, and potential injuries. To sustain the results achieved through the 5S approach, it is essential to internalize each step and make it the way things are done on a daily basis.

The vision is to have 5S implemented everywhere, at all levels of the organization. The Montecchio site has an implementation plan for 5S in the Model Cell and subsequently across the entire site.

5S training is provided to all employees so that they can later apply what they've learned in the workplace and lead 5S activities. Afterward, a regular 5S audit plan (self-audits, cross-audits) is implemented over a specific period of time (weekly, bi-weekly, monthly). There is clear documentation on the 5S procedure and standard work, with the use of the global 5S audit form, which has defined criteria and a scoring method.

Following the audit, the main 5S dashboard is posted in the area, showing the results of the audited area and the actions to be taken based on the findings during the audit.

3.2.6 Standard Work

Standard Work is a description of how to perform a specific task in the most efficient way to carry out a recurring activity, or to perform tasks without waste through the best combination of work methods. It ensures fairness among employees, with equitable and consistent results and expectations. In fact, if everyone performing a specific task does it the same way, the outcome should be more predictable in terms of time, quality, and safety, which also makes training new employees much easier. Ideally, Standard Work should be defined for all tasks performed by more than one person, documenting changes and preserving knowledge.

Standard Work is characterized by three elements:

- Takt Time: the pacemaker for production.
- Sequence: a repeatable sequence of operations.
- Work In Process (WIP): a defined amount of WIP necessary to maintain process flow, ensuring Just In Time (JIT).

Currently, at the Montecchio Maggiore site, Standard Work is implemented in both the offices and the production area. To reach the target score for next year, following a peer assessment, WIP and Takt Time are being integrated into the Standard Work, starting with the calculation

of WIP and TT in the model cell (SCUBA assembly line (Figure 3.1) and Nava automatic press line WCP) before extending it to the entire production area.
All documents are visibly posted in the work area, and employees are trained in using this tool.

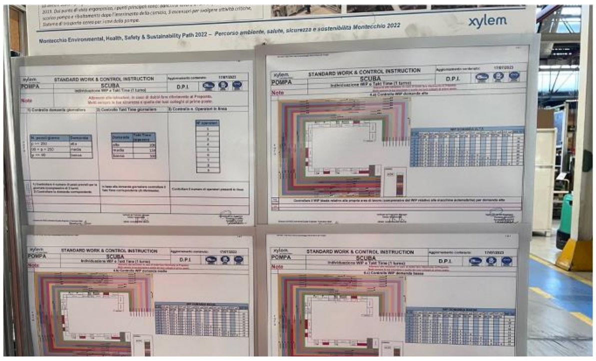

Figure 3.1: Standard Work WIP and TAKT TIME of SCUBA assembly line

3.2.7 Total Productivity Maintenance

Preventive maintenance is useful for maximizing the capacity, quality, and productivity of equipment and processes, and for improving operational reliability and flexibility through employee involvement. The vision is to have actual delivery times identical to planned delivery times, thanks to the high level of predictability in machine output.

A plan is made to identify critical equipment, as its downtime would prevent the company from reaching its objectives. This equipment often impacts safety, regulatory compliance, costs, and operational productivity. The steering committee agrees on which indicators will be reviewed monthly to assess the health of the preventive maintenance program. For example, some of the indicators periodically reviewed include machine downtime rate, OEE[4] (Overall Equipment Effectiveness), Mean Time Between Failures (MTBF[5]), etc.

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[4]Overall Equipment Effectiveness, also known as OEE, is a manufacturing and production Key performance indicator (KPI) used to measure the efficiency and effectiveness of machinery, production lines, and manufacturing facilities. OEE is great for providing an overview of equipment performance by using availability, performance, and quality metrics. (Muchiri, et al., 2008)
[5]Mean time between failure (MTBF) is a measure of the reliability of a system or component. It's a crucial element of maintenance management, representing the average time that a system or component will operate before it fails. It is calculated by dividing the total time of operation by the number of failures that occur during that time.

3.2.8 Kaizen Event

Kaizen events are continuous improvement events that are regularly conducted, well-planned, with a defined business case. These are intensive, small-scale improvement projects that are tightly focused and time-limited (usually no more than a week, often less).

Kaizens are specifically designed to bring incremental changes; in fact, there might be a series of kaizen improvement events that repeatedly focus on a single small area. The results are cumulative, progressing step by step to improve production flow, ease the physical tasks of operators, reduce setup times and inventory, and improve quality. The goal is to achieve immediate improvements in the system and processes.

Kaizens are customer- and business-focused, carried out through observation and learning-by-doing, and executed by the people who do the work to ensure acceptance and promote skill development. The vision is to embed continuous improvement (CI) in everyone's DNA, and ensure that support is driven by effective cross-functional teams.

Unlike Kaizen workshops that may be organized to address immediate needs, there is typically an annual strategic plan decided by the steering committee. For each workshop, the "3-1-3 method[6]" is applied, and events requiring preparation and alignment with the schedules of other employees are proactively planned.

The results of Kaizen events, along with before and after photos, are shared, published in the area, and communicated to all involved parties. The team leader/process owner schedules a meeting to present the Report Out to the site management and the Continuous Improvement (CI) community.

3.2.9 Problem Solving

This approach involves addressing opportunities systematically through an 8-step process. The vision is to identify the root causes of the problem and then implement future states/actions to improve business metrics. The A3 activity can be used to address immediate needs as well as complex problems. Each A3 problem resolution is posted in the location where the problem was solved (on the SEQDPI card of the cell), and a summary is reported on the A3 problem-solving dashboard in the Obeya room, or an equivalent space.

[6] Preparation, duration, and review process for a standard Kaizen: 3 weeks before the Kaizen week are dedicated to preparation, then 1 week for the Kaizen itself, followed by 3 weeks to ensure a sustainable process.

One of the roles of a CI (Continuous Improvement) leader is to teach operators, supervisors, and team leaders how to recognize improvement opportunities, and then how to act on them using their own resources. CI professionals often provide advice and support to teams, but most of the work is done within the teams themselves, which is one of the reasons why PPS (Practical Problem Solving) events are such powerful training vehicles. Problem-solving and lean practitioner courses are held periodically to train employees on the techniques and tools of continuous improvement.

3.2.10 Visual Management and Manage Daily Improvement (MDI)

The site's areas have specific objectives aligned with the company's goals, which are monitored through the SEQDPI system. This system translates the company's objectives into clear and measurable daily activities, allowing the areas to meet these targets. As a visual management tool that tracks process performance day by day, it enables the identification and communication of any issues directly to various business departments. Anyone standing in front of an SEQDPI board can understand the performance of the cell under review.

A team made up of individuals from different company functions (quality, production, internal logistics, continuous improvement) dedicates an hour and a half each day to analyzing the data collected using this method. Once a week, the multifunctional team reviews all SEQDPI boards, and together with the operators, they assess the problems that arose during the day to see if any critical issues have emerged. The goal of this model is to make problems visible so their root causes can be identified and eliminated, while also spreading problem-solving skills.
Additionally, in every CFU (Cost Focused Unit), there are also Suggestion Boards (Figure 3.2) designed to collect any input from employees that could contribute to current processes. The suggestion system allows anyone with an idea for improvement that impacts safety, the 5S (Sort, Set in Order, Shine, Standardize, Sustain), quality, market share, and/or efficiency to fill out a card indicating the difficulty encountered and/or the opportunity to seize, its cause, and the benefit of implementing the idea.
All collected ideas are visually tracked on the board (Figure 3.3), following the PDCA cycle and documenting the journey from idea formulation to standardization. Each idea is managed by a team that meets weekly to assess the feasibility of new suggestions, schedule them, ensure their implementation, and verify proper functioning. Every implemented idea is formalized into a Point Kaizen, which is linked to moments of recognition and sharing to spread, transfer, and sustain the culture of improvement.

The vision is that all employees understand the company’s goals and know how to contribute.

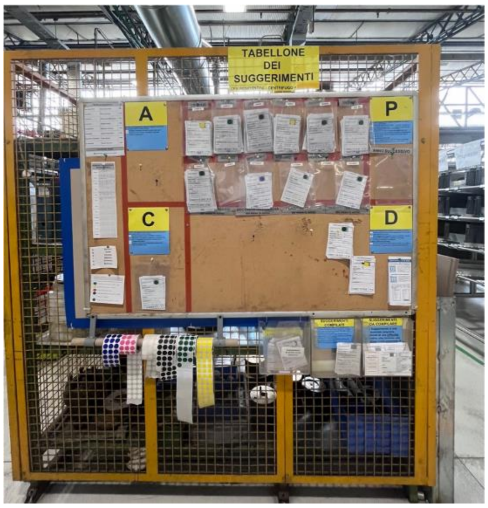


Figure 3.2: Suggestions Board

Figure 3.3: SEQDPI board

3.2.11 Value Stream Mapping (VSM)

Value Stream Maps (VSM) are used throughout the company. All activities, both value-added and non-value-added, are evaluated from the customer’s perspective, and the company works on initiatives that support the future state of the Value Stream Maps. The vision is for the organization to adapt to the future state VSM to drive and support an end-to-end vision, ultimately leading to customer satisfaction. As a result, the VSM must be adjusted according to changes or business needs.

Creating "Current State," "Future State," and "Ideal State" is not merely an academic exercise but is used to document, analyze, and improve the flow of information or materials needed to produce a product or service for a customer. It can be applied to any "value chain" where the team seeks to improve the flow of materials and information. It is important that employees understand how to "read" and interpret the VSM, which are posted in each critical area, starting from the model cell.

3.2.12 Continuous Flow

This element aims to emphasize the concept of continuous flow, where the next step in a process is initiated as soon as the previous one is completed; no batch processing and minimal work-in-process. The stages of the process are also located close to each other to avoid unnecessary transportation. Indeed, the work centers on the site are designed with an optimal layout, typically U-shaped, to ensure continuous flow.

The vision is that the overall work is balanced in a synchronized one-piece flow. To this end, all employees are trained in continuous flow techniques, which explain the use of tools such as spaghetti charts, process maps, motion studies, waste walks, etc.

At the core of this is the development and construction of the site layout, which is organized with the connection of processes to enable the correct flow of materials (as much as the environment/building allows). At the Montecchio site, the production area is organized into two Continuous Flow Units (CFU), "Residential" and "Commercial," where the assembly lines and machines producing semi-finished products are placed in close connection, and the downstream station provides information to the upstream one for production. The two CFUs are distinguished by the types of products made and their subsequent use: small sizes for residential use in the first case and large sizes for commercial use in the second.
Within the two CFUs, six macro-flows, or SUB CFUs, can be distinguished, in which the various products produced are categorized:

- **SUB CFU 04 "Stamping"**: production of steel semi-finished products for feeding processing and/or assembly lines.

- **SUB CFU 05 "Multistage"**: assembly of vertical multistage pumps (series e-SV, SVI), laser welding, and mechanical processing.

- **SUB CFU 06 "Industrial Centrifugal"**: assembly of centrifugal pumps for industrial applications (series HM, SH/FH).

- **SUB CFU 07 "Residential Centrifugal + Drainage"**: assembly of centrifugal pumps for residential applications (series CA, BG) and assembly of pumps used for draining dirty water (series DOC, DOMO, DIWA, SCUBA).

- **SUB CFU 09 "Winding and machining"**: processing of copper wires to create motor windings, mechanical processing on lathes for feeding assembly lines.

- **SUB CFU 10 "Booster"**: assembly of pressure groups.

Each production flow is then divided into "work centers" (abbreviated as WC), which are dedicated work centers for a specific technological process within which a certain number of semi-finished or finished product codes are produced; each work center is associated with an identifying number.

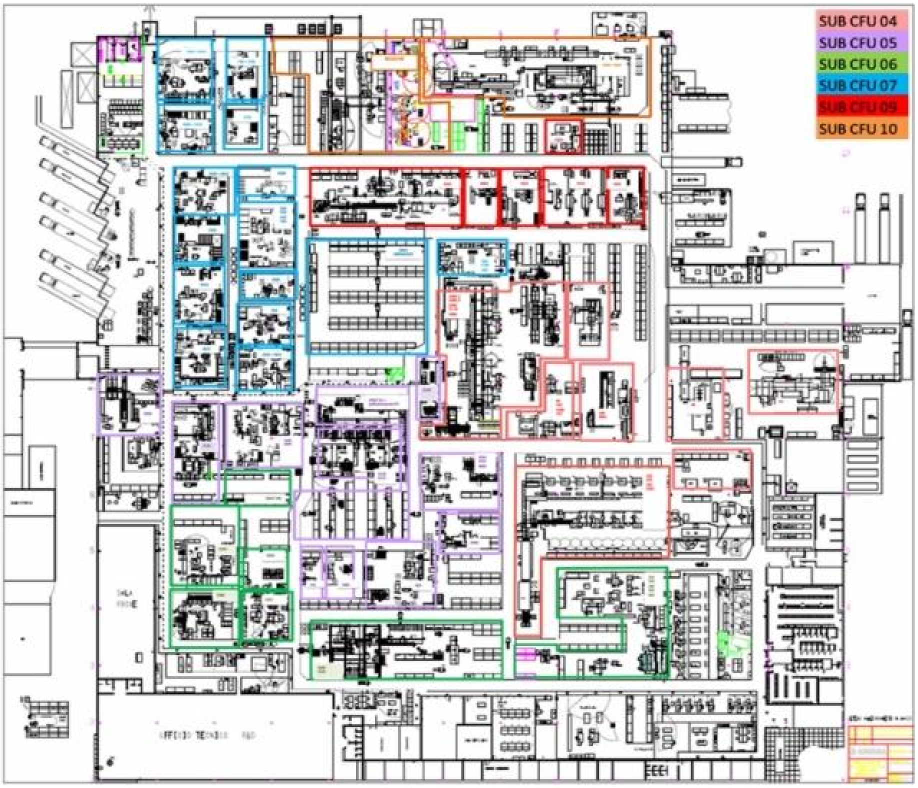


Figure 3.4: Production area and SUB CFU division

3.4 Conclusions

This chapter explores the Xylem Production System, a system-wide adaptation of lean principles that is intended to standardize and improve operations globally.

The SEQDPI pillars, that is, Safety, Engagement, Quality, Delivery, Productivity, and Inventory, are elaborated upon as a set of crucial improvement areas.

The chapter also highlights continuous improvement as the lifeblood of XPS, with maturity assessments and internal audits guiding this company's approach in aligning its business with lean principles and driving consistency in operations.

Chapter 4

Model Cell: Definition and Characteristics

Apart from what has been stated in the previous chapters, this one will provide the definition of a model cell, which is the aim of this thesis. This will be done by addressing some other characteristics and definition in addition to the one already described, crucial to understand at the best the processes that are going to be described in the case study.

This chapter will have brief repetitions that are necessary to contextualize what is described, keeping in mind that lean management is not just a set of tools but a way of thinking, doing, improve. That is said because there are steps to follow in order to have effective results, but that is not enough because some steps need to be taken synchronously to create the synergy that will improve the process.

In the end, some important tools for project management will be presented, that is needed as an introduction due to their crucial role while developing the project this thesis is about.

4.1 Model Cell definition

Before undertaking a lean transformation, some companies prefer to implement a model cell, meaning they select a cell or business area in which to experiment with lean techniques. This approach allows management to conduct experiments and address emerging issues while studying the ideal solution.

In fact, it is the best way to help people learn by giving them the opportunity to engage with the tools, principles, and characteristics required for transformation. Therefore, the model cell becomes the company's learning center, as it represents the model the organization must follow. Another advantage of implementing a pilot cell is the spread of enthusiasm among people regarding the transformation process that will follow. This atmosphere is crucial for supporting change and also paves the way for future model cells, which will address different types of problems.
This is the first step in spreading lean thinking within a company, which would otherwise be slowed down without a model cell.

We can identify two phases in using this approach (Toussaint, 2015; Pampanelli et al., 2014):

- Pilot test phase: A cell is identified—the model cell, precisely—where new techniques are tested, and new concepts are put into practice to verify their validity before launching them in several other production cells, confirming the prerequisites and analyzing the potential benefits.

- Roll-out phase: What was tested in the previous phase is applied to various production cells (in the case of a manufacturing company) or, more generally, extended to other business areas. The model cell must serve as a demonstration to "sell" lean and apply the new methods to the rest of the company.

The model cell will also be a topic of debate between those we can call early adopters of change and the "sceptics"

According to John Toussaint in "Management on the Mend" (Toussaint et al., 2015), to choose the pilot area, one must focus on a process/problem relevant to the business where new techniques are to be tried to move in the direction of the "true North." The model cell should be “an inch wide and a mile deep,” with well-defined boundaries, leaving no doubt about what is in scope and what is not.
It is crucial for senior leadership to be engaged in the project, and an action plan must be created for the implementation of new tools and techniques. To more effectively visualize the changes, the "before" and "after" should be documented with photographs.

To understand where to begin, it is useful to ask five questions identified by John Shook (2007) in defining the Lean Transformation Model (Figure 4.1):

1. What is the purpose or problem we are trying to solve? What value are we creating?
2. How do we improve the current work?
3. How do we "develop" people?
4. What leadership behaviors and management systems are necessary to support this new way of working?

5. What principles or basic assumptions are behind this transformation?

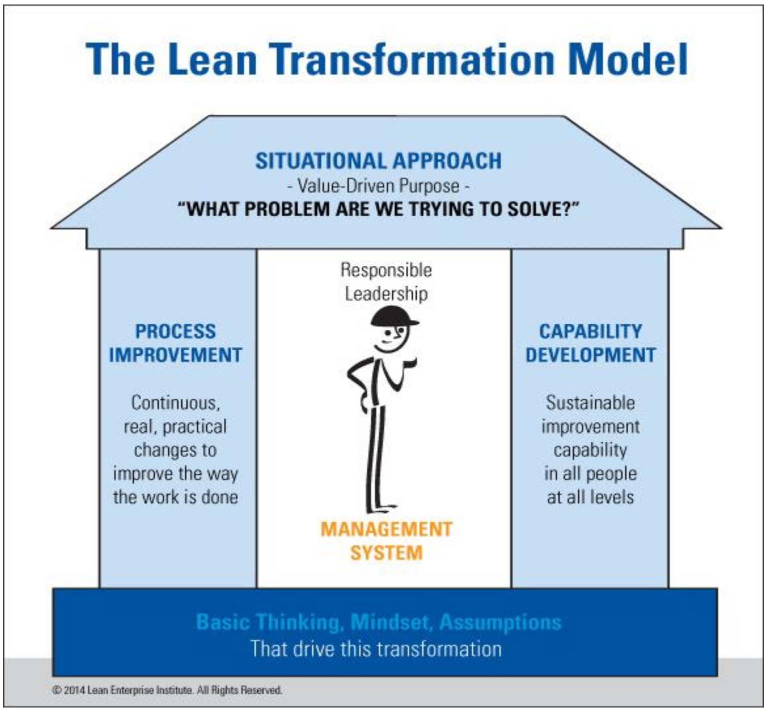


Figure 4.1: The Lean Transformation Model

1. When asking what problem we want to solve, we must consider the organization's goals so that the model cell experiment aligns everyone with the company's broader objectives and creates a new system based on standard work that supports improvement. It is important to ask repeatedly whether the chosen problem is still worth solving, and agility and the ability to change direction, if needed, are essential.

2. Process improvement, in the design of the Lean Transformation Framework house, supports the roof, which represents the problem to be solved. The concrete process improvements implemented must support the broader goal. The most difficult milestone to achieve will be transforming everyone's thinking into an experimental mindset. Experimenting requires more energy, and people won't do it naturally. Thus, a true cultural change is necessary, which will be discussed later. Once a significant part of the company has mastered various Lean management tools, it is time to start thinking big scaling up Lean principles and practices, which is quite complex.

3. "Building capability" is another way of saying "developing people." All the work is done by people, which is why the second pillar of the Lean Framework is people development. You can't improve the organization without growing the people within

it. Even more importantly, it is the people who must conduct numerous experiments and continuously improve processes, as mentioned in the previous point.

4. There is no doubt that leadership plays a central role in implementing a lean transformation. Leadership occupies the inside of the Lean Transformation house, interacting with the entire system to make it better, while the system protects it from external cold.

4.2 Manual Assembly Lines

Since the paper is based on a project in a manufacturing context, specifically in a metalworking company, the model cell will be a production line where pumps are assembled.
An assembly line consists of workstations that can be arranged along a conveyor belt or other material handling systems. Parts are processed consecutively along the line and moved from one station to another. At each station, specific operations are repeatedly performed, adhering to the cycle time (the maximum time available to complete the tasks assigned to the station).
Manufacturing a product on an assembly line requires the division of the total amount of work into a series of basic operations called tasks. The execution of a task requires task time and specific equipment and/or operator skills. Due to technological and organizational conditions, precedence constraints between various assembly tasks must be observed (Becker et al., 2006).
In this paper, the terms "cell" and "line" will be used synonymously.

There are three types of assembly lines (Figure 4.2):

- **Single-model:** The line is dedicated to assembling a single product.
- **Multi-model:** Different products are assembled on the same line, with batches of products processed and interrupted by setups. The time losses caused by setups necessitate batch production.

- **Mixed-model:** A family of products is assembled on the line without stopping for setups, thanks to the products' design similarity.

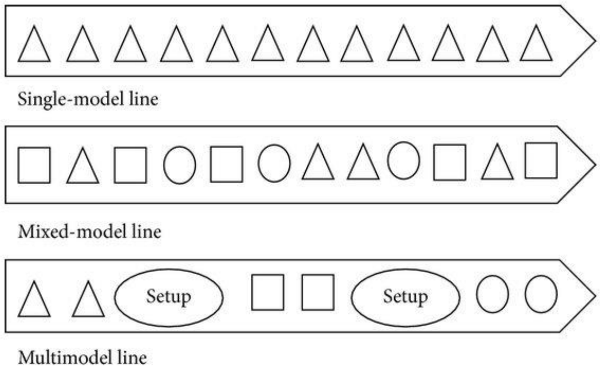


Figure 4.2 Assembly Line Solutions

First of all, it is necessary to choose which finished products to assign to a cell, and to do so, some guidelines can be followed (Rother et al., 2001):

1 <u>Flexibility</u>: If demand shifts between products and setup times are low, it is better to divide the products among "mixed-model" cells. However, if demand for a given product is sufficiently high, it is preferable to dedicate a cell or line to that single product. The total production capacity remains the same in both cases, but the ability of each process to adjust to demand fluctuations between products is much greater in a mixed-model line. This is because, while demand for an entire product family may often be stable, the demand for an individual product within the family can vary significantly.

2 <u>Variations in total work content</u>: The man-hours required to process a part from start to finish, known as the total work content, should not vary by more than 30% among the different finished products produced within the cell. Otherwise, it becomes difficult to maintain flow and productivity.

3 <u>Similar process steps and equipment</u>: Products processed within a cell should have similar assembly steps and require the same equipment to ensure continuity of flow and maintain the desired level of productivity.

4 <u>Takt time (production rate)</u>: This is the pace at which customers demand products and is calculated by dividing the total available time in a shift by the quantity requested by customers during that shift.

$$Takt\ Time = \frac{Available\ production\ time}{Customer\ demand}$$

When high demand requires very short takt times, it is worth considering the use of multiple cells, preferably located near each other, instead of a single cell working at high speed. As a general guideline, when the takt time of a cell drops below 10 seconds, the operators' work becomes highly repetitive and stressful; conversely, when it exceeds 120 seconds, the number of tasks becomes so large that it can be challenging to standardize the work method, and it becomes difficult for operators to have all the components for each variant of the finished product readily available on the line.

5 Customer location**:** When customers for a product are geographically dispersed, it might make sense to divide the work into different lines, each located near the customer, to reduce shipping costs and delivery lead times.

4.2.1 Takt Time and Operator Balance Chart

Takt is a German word that means rhythm or beat, also used to mark the musical tempo conducted by an orchestra's baton. *Takt time* is a reference number used to synchronize the production cadence of a process with the sales rate. It is expressed in seconds per unit, just like the cycle time, which represents the actual production rate. *Cycle time* refers to how often a finished piece exits the end of the cell. Often, processes are run at a cycle time faster than the takt time, as a precaution against potential slowdowns due to underperforming equipment or other issues during the shift.

However, if the cycle time is much shorter than the takt time, there is a greater chance of overproduction and excess use of operators, as well as hiding production problems and reducing the incentive to identify and eliminate the underlying causes.

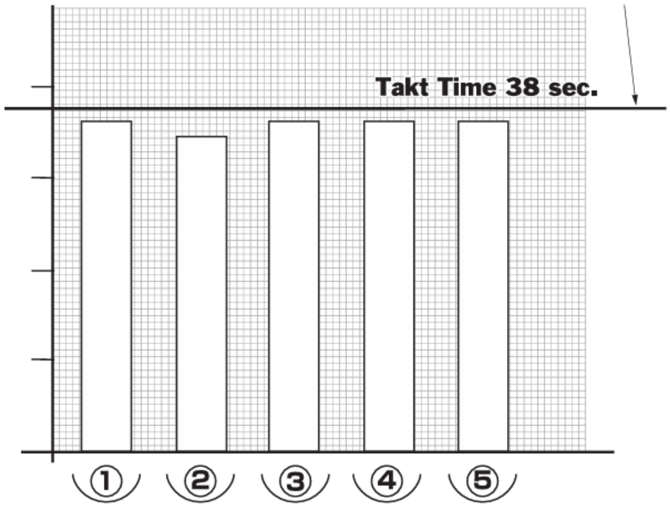
Takt time, which represents customer demand (which cannot be controlled), is divided over the available production time (which can be adjusted) and can be changed by modifying:

- The available production time, which is the number or length of the shifts,
- The number of finished products produced in the cell,
- The number of cells producing a specific finished product.

To determine the actual time required for each work element, it is necessary to go to the gemba and directly measure the time for each activity with a stopwatch[7]. Collecting information firsthand directly at the gemba helps to understand the real situation and identify waste that would otherwise remain hidden. For the data to be meaningful, each activity should be measured multiple times. The following suggestions can be followed when measuring times:

- Collect real times directly from the process.
- Position yourself so you can clearly see the operator’s hand movements.
- Record each work element separately.
- Observe a qualified operator (e.g., the line reference).
- Always separate operator time from machine time (if applicable).
- Select the lowest repeatable time for each element.
- Remember to be courteous on the shop floor (Rother et al., 2001).

Based on the work elements and the recorded times, it is possible to create a very useful tool called the Operator Balance Chart (OBC), also known as the operator balancing table or Yamazumi Chart (Figure 4.3).



Assemble 1	Forming	Assemble 2	Tester	Appr.	Total
37	36	37	37	37	184

Figure 4.3: Operator Balance Chart

The Yamazumi chart represents the distribution of work among operators in relation to takt time, based on the real data recorded by the team and appropriately processed. It is a

[7] To define standard times, there are direct measurement methods, such as Bedaux and work sampling, and indirect methods, such as MOST (Maynard Operation Sequence Technique) and MTM (Methods-Time Measurement).

quantitative, simple, and visual tool that helps generate ideas for efficiently balancing cells and improving continuous flow.

An OBC uses vertical bars to depict the total amount of work each operator must perform in relation to the takt time, represented by a horizontal line. The vertical bar for each operator is constructed by stacking small bars that represent individual work elements, with the height of each element proportional to the time required. Creating a chart in this way is useful for redistributing work elements among operators. This is essential to minimize the number of operators needed while ensuring that the amount of work for each operator is nearly equal, but slightly less than the takt time (Lean Enterprise Institute, 2020).

To calculate the number of operators, the following formula is used:

$$Number\ of\ Operators = \frac{Work\ Content}{Takt\ Time}$$

In most cases, the result of the formula is not an integer; therefore, Rother and Harris suggest proceeding as indicated in the table:

Residual from n° of operators calculation	**Guidelines/Objective**
< 0.3	Do not add another operator, try to reduce wastes and non-value added activities even more
0.3 – 0.5	Do not add another operator. Test for two weeks in real working conditions while trying to evaluate if there are enough wates that can be eliminated with kaizen actions.
> 0.5	Add another operator and keep working on evaluation of wastes that can be eliminated, maybe in the long run you will be able to do it

Table 4.1: Guidelines for non-integer number of operators results

4.2.2 Value Added and Non Value-Added Activities

The concepts of Operator Balance Chart and Tak Time has been previously explained, and they are needed in order to have an assembly line that can at the same time be balanced (no bottlenecks) and fulfil customer demand.

An assembly line that is not properly optimized will for sure have Non Value-Added Activities among the process that it is done inside of it.
The Cycle Time is made of three kinds of activities in terms of value added to the process:

- *Value-Added Activities*

  These are the activities that are performed in way in which every part of them adds value to the process, the aim of a good waste analysis is to get as close as possible to 100% of only value-added activities.

- *Non Value-Added Activities*

  These are those kinds of activities that are considered a waste, they do not add value to the process and can be defined as "what the customer is not paid for".
  They can be identified if they do not meet all the three following criteria (Learn Lean Sigma, 2024):
  1. They transform people, information, or materials.
  2. They are done right the first time.
  3. The customer wants it and is willing to pay for it.

  These are represented by the seven MUDA and the aim is to get the percentage of them as close as possible to 0% of the process.

- *Incidental Activities*

  These activities are also called Necessary Non Value-Added Activities, that is because they do not add value to the process and from the outside they can be seen as non value added activities. The difference is that they cannot be eliminated (at the moment of the analysis) because of certain constraints induced by hardware, software, etc. make them necessary in order to properly perform process.
  This is the tougher kind of NVA because there are intrinsic characteristics of the process that make them hard to be eliminated, leading to a not completely optimized balance.

4.2.3 Continuous Flow

When it comes to dealing with batch quantities that flow through the line, it is possible to identify two main logics, the second one is the one that needs to be implemented when structuring a Model Cell:

- <u>Batch Manufacturing</u>

  In this kind of logic, a group of products (batch) goes through the process as one entity, along with any defects that may exist. The get to the end of each phase at the same time, making it vulnerable to defects that are late discovered, forcing to reworking not only one piece but the whole batch.

- <u>Continuous Flow</u>

  On the other hand, this logic implicates that each product goes through each phase of the process in a one-piece batch, so that defects can be corrected earlier in the process. Along with that, fewer products would require rework (Constable, 2024).

4.2.4 Standardized Work

A crucial point when building a model cell is to eliminate everything that can be identified as a disruptive element in the process.
This is done by standardizing the process: if a process is fully standardized and there is no space left for deviancy, then it is close to impossible to have unexpected events that can create bottlenecks and stop the continuous flow.

Standard alone is not the one and only answer, because you standardized the process but things that are intrinsic of lower-level parts can create a product nonconformity that a standard process later in the supply chain cannot prevent.
This needs to be done before, standardizing the phases that are located earlier in the production sequence.

Standard is good, with standardization of processes you eliminate what can unbalance the flow, and by doing that you can plan better, and by planning better you can reduce your lead time by keeping the same level of quality every time, and with this thing you will achieve what is crucial to be profitable: customer’s satisfaction

4.3 Project Approaches

When dealing with a project like times, organization and diligence is priority. The steps to the final outcome are multiples and not having them set in order could potentially lead to lose track and not get to the point in the most effective way.

To do that, these are some of the tools that helps the execution of all the phases.

4.3.1 Advanced Product Quality Planning

APQP (Advanced Product Quality Planning) is recognized as the structured method by major automotive industry manufacturers for implementing advanced quality planning during product and process development management, from the launch of the initiative (Kick-off) to the validation of the product and process before starting mass production.

APQP can also be defined as a multidisciplinary approach to quality planning that fully integrates quality tools with the quality management system.

According to the Automotive Industry Action Group (AIAG), the purpose of APQP is to "produce a product quality plan that supports the development of a product or service capable of satisfying the customer (Zhao, 2011).

The main benefits of this set of activities are: directing all individuals involved towards customer satisfaction, promoting early identification of necessary changes, avoiding late changes, and delivering a quality product on time at the lowest cost.

APQP consists of five macro-phases, which follow the Deming cycle:

1. Planning and definition: The goal is to determine where you want to go. It involves identifying customer needs, requests, and expectations using tools such as QFD (Quality Function Deployment) to review the entire quality planning process.

2. Product design and development: This phase answers the question, "Can we design it?" and involves performing a D-FMEA (Design-Failure Mode and Effects Analysis), defining product specifications, and conducting design verifications.

3. Process design and development: This phase aims to determine if the product can be produced. From the P-FMEA (Process-Failure Mode and Effects Analysis), the control plan is defined, along with the process flowchart, process management, and process capability control (initial statistical study, control charts, data analysis, etc.). These activities depend on the completion of phases 1 and 2.

4. Product and process validation: This involves validating the process and product (essentially testing phases 2 and 3) and presenting the sample to the customer as required by the PPAP (Production Part Approval Process) manual.

5. Final evaluation of the project and process: Feedback is evaluated, and corrective actions are implemented to enable continuous improvement of the process and product, aiming to achieve full customer satisfaction.

4.3.2 FMEA

The FMEA (Failure Mode and Effects Analysis) technique evaluates potential "failures" of a product or process and their effects, identifies what actions can be taken to eliminate or minimize errors and malfunctions, and documents the entire procedure. This tool is used from the initial planning stages through to the design, manufacturing, and end of a product's life.
FMEA is undertaken to continuously improve products, processes, and reliability, thereby increasing customer satisfaction. The goal of FMEA is to identify the critical factors of various failures/errors to prevent them. Along with other quality tools, FMEA supports the practice and philosophy of problem prevention and continuous improvement, which are key elements of Total Quality Management (TQM).
For each type of failure, three indices can be estimated:

- Occurrence index (*O*): Answers the question, "What is the likelihood that the failure will occur?"

- Severity index (*S*): Answers the question, "What would be the consequences of the failure to be?" and gives an indication of the impact the failure has on the system.

- Detection index (*D*): Answers the question, "How likely is such a failure to be detected before it affects the customer??" It refers to the available means of detecting the failure (Slack et al., 2022).

For each potential failure cause, the product of these three indices is used to calculate the Risk Priority Number (*RPN*), which provides a measure of risk. It is used to highlight the failure modes that need to be addressed, starting with those with the highest RPN (Slack et al., 2022).

$$RPN = S * O * D$$

FMEA can be applied to different systems (Johnson et al., 2003):

- *Design/Product FMEA or D-FMEA (D = design)*: Used during the definition of functional specifications to identify and correct potential design weaknesses that may lead to failures, problems, or malfunctions during the use/application of the product. For each group or functional component listed in the bill of materials, the functions of the product are associated, which must be identified in order to detect all potential failures, such as delay, anticipation, degradation, or absence of a component function. Compared to P-FMEA, this is a more preventive approach, typically used for complex products/durable goods.

- *Process FMEA or P-FMEA (P = process):* Used during the definition of process specifications and the manufacturing range to highlight and correct potential risks and losses related to the process, which can affect product quality. This is a more corrective approach compared to D-FMEA and is more commonly used for simpler/consumer products.

4.3.3 Project Management Tools

Several project management tools were used to carry out the project, which we will briefly review in the following lines:

Project Charter: This is prepared during the project mission definition phase to establish objectives, the project team, scope of study, and key timelines (for example, the kick-off date and the estimated project completion date).

Gantt Chart: A graphical representation of a project timeline, useful for planning, coordinating, and tracking specific actions within a project, providing a clear illustration of the progress. Each task is represented by a horizontal bar, whose length is proportional to the task's duration. This allows you to see which tasks can be done in parallel and which are sequential. As the project progresses, colored bars can be added to the chart to indicate completed tasks or portions of completed tasks, while a vertical line is used to mark the reference date.

Kick-off: This is the meeting that serves as the starting point for a project, task, or activity. It involves all the people who might be engaged in the project, aiming to align them on the goals, expected results, tools, timelines, roles, and methods. In summary, it's a meeting to both inform and motivate participants towards the successful completion of the project.

Meeting Minutes: These are the written records of meetings and are used to inform both participants and non-participants about what was discussed or what occurred during the meeting. Typically, the person facilitating the project is responsible for drafting the minutes, which include information such as the names of participants, agenda items, decisions made, follow-up actions with their respective owners, deadlines for task completion, and any other discussions that should be documented for future reference or historical tracking.

4.4 Conclusions

The model cell serves as a practical demonstration of lean efficiency, allowing for a controlled setting to test and implement lean principles.

This chapter describes its features, including standardized work, takt time synchronization, and continuous flow.

The entire chapter described the model cell and its characteristics, as serving a role in the reduction of waste, improvement of material flow, and creation of a replicable framework by which production processes are optimized.

Chapter 5

Case Study: Background and AS IS configuration

This chapter starts to explain the roots of the project, describing the background of the cell that had been chosen for the lean transformation in analysis. The actual configuration and of the cell ad its issues will be presented, along with the products range.

5.1 Background

Advance Water System has a global strategic plan going on for a few years, defined year by year to achieve a stronger and more complete implementation of the continuous improvement philosophy, pushed by the Advance Water System CI team who looks forward to become the best one in sharing the continuous improvement culture in all the Xylem's sites.

The Montecchio Site Transformation Plan for 2024 has different objectives, one of them is the one that this thesis talks about: Model VSM on the HM cell.
The HM cell has been selected as the one to start with the VSM identification and Model Cell implementations using four metrics (Figure 5.1):

- Cost of Goods Sold (*COGS*)
- Complexity of the stream
- Potential to Grow
- Team Readiness to start the study

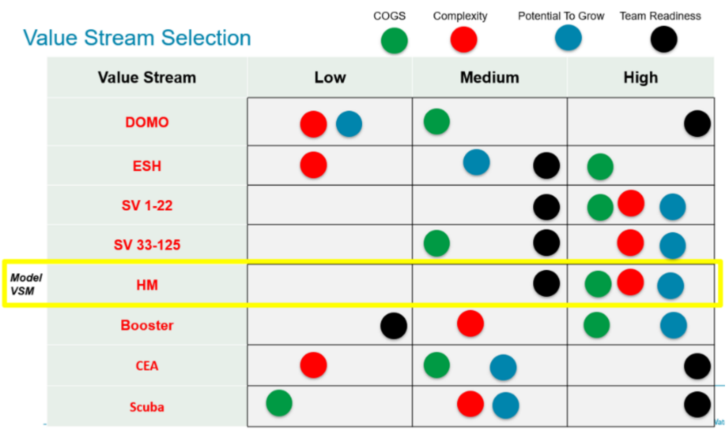


Figure 5.1: HM selection for VSM

The HM cell contains two assembly lines: eHM and HM with sleeves.

eHM line was chosen as the pilot only because starting with HM with sleeves would have been too challenging, starting with eHM line was the wisest decision in order to approach the other line with more experience.

5.2 Objectives

The macro-level objective of the project is to study, experiment, and teach new techniques and principles within the model cell, which serves as a pilot area, to then extend them to the rest of the company.

Going into detail, the macro-objective can be broken down into three goals:

- Raising the culture of continuous improvement within the plant, recognized as the source of the entire initiative. Specifically, we aim to meet targets for implementing the 5S (according to Xylem's Audit system), ensuring that all work instructions (standard work) are complete, up-to-date, and followed by operators, and, finally, applying tiered accountability to track problems, identify root causes, and propose solutions to eliminate them.
- Validating a method of line servicing aligned with the company's vision, which involves continuously improving production process efficiency and optimizing internal supply flows through the plant's relayout. The aim is to create a single direction of material flow within the plant, positioning assembly lines near the loading bays, with their respective supplier work centers immediately upstream.
- Take to the minimum the waste, creating continuous flow and making materials flow in an optimized manner. Create an environment in which the flow cannot be broken from factors that are unpredictable, having a route for even the smallest tiny object that circulate around the factory.

5.3 Project Team

For the realization of the project, a team of people from different functions of the company has been defined, to fully exploit the advantages that team working gives, such as sharing knowledge, methods and competence, distribution of workload and problem solving.

In fact, everyone brought in the group its know-how and point of view, creating incentive for confrontation and exchange.

The Project Team (Figure 5.2.) as a macro-organization is defined so that roles and responsibilities are cleared, making sure that alignment between the people involved is efficiently done.

SPONSOR	Site Leader
PROJECT LEADER	Operations Manager
FACILITATOR	CI Specialist
PROJECT DESIGN	Schedule Manager (**Team 1**)
	Logistic Manager (**Team 2**)
	Production Manager (**Team 3**)

Figure 5.2: Project Team Structure

The Project Team is divided into three core teams (Figure 5.3) that are responsible for three different areas, which need to work in parallel and with continuous communication between the three teams.
In this case this role is assured with a CI specialist working as a facilitator.

The three teams were defined as:

1. *PFEP* team: dedicated to creating a database containing all the information regarding materials and analysing the optimal way of scheduling.
2. *Material Movement* team: dedicated to analysing the internal flow of material and finished goods.
3. *Manufacturing* team: dedicated to addressing manufacturing capacity, process constraints and design the assembly line to create continuous flow.

PFEP Database and Scheduling – Team #1

Goal: Address data collection and populating an initial PFEP database (Plan-For-Every-Part) supporting the selected value stream

- Create the PFEP database with a least 100 or more part numbers
- Apply all PFEP principles
- Create a production schedule / loop using:
  - Easy, Medium, and Difficult
  - Runners, Repeaters, and Strangers

Address Needs and Use Tools:

- Optimizer
- Level Scheduling
- Purchased Supermarket Sizing
- WIP Market Sizing
- Kanban Loop Size for Purchased and WIP materials
- Size FIFO Lanes
- Set FG Strategy and Sizing

1.PFEP	R	A	C	I
Schedule Manager	R			
Operation Manager		A		
Logisitic Manager			C	
D.M. Purchasing Manager			C	
Master Planner			C	
Buyers, Planners			C	
CI Specialist			C	
CI Manager				I
Production Manager				I
Site Leader				I

Material Movement - Team #2

Goal: Address Material Movement within the Value Stream and consider use of tuggers or manual material handling, containerization, Kanban pulls, production loops, and point-of-use delivery

- Prepare to address line side delivery to operator's point of use
- Design and set material delivery routes using a coupled route
- Create all the material move signals / triggers identified with Kanban cards or other readily identifiable visual signals

Address Needs and Use Tools:

- Plant-wide Address System
- Purchased Parts Supermarket Layout
- WIP market Layout
- Determine Storage Design & Devices (racks, containers etc)
- Design and Make Pacemaker Scheduling Board
- FIFO Design and Layout
- Design Tugger Routes

2.Material Movement	R	A	C	I
Logisitic Manager	R			
Operation Manager		A		
Schedule Manager			C	
Production Manager			C	
Industrialization Manager			C	
Maintenance Manager			C	
Quality Coordinator			C	
CI Specialist			C	
CI Manager				I
Site Leader				I

Manufacturing - Team #3

Goal: address manufacturing capacity and productivity constraints, standardized work development, work cells, cellularization, loop optimization, and WIP markets

- Create Job Instructions / Job Breakdown Sheets
- Create Operator / Machine Balance Charts
- Reconfigure work cell incorporating initial waste elimination opportunities and material flow improvements
- Production loop – optimize change-over sequence
- Create Pull trigger board, trigger points, WIP, buffer, safety stocks

Address Needs and Use Tools:

- Work Place Organization (5S-Standardization-Visual Factory)
- Cell Design, SMED, TPM
- Develop Correct Standards (TWI to Standardized Work)
- Day by Hour Charts and Tracking
- Productivity Improvements

3.Manufacturing	R	A	C	I
Production Manager	R			
Operation Manager		A		
Master Planner			C	
Item Master			C	
Maintenance Manager			C	
Quality Specialist			C	
Quality Coordinator				I
CI Specialist				I
CI Manager				I
Site Leader				I

Figure 5.3: Goals, Needs, Tools and RACI of the three teams

The time that concentrated on the part of the project that paper is about, is the Manufacturing Team (Team 3).

5.4 Harris Lean Systems

Founded in 1995, Harris Lean Systems, Inc. (HLS) (Figure 5.4) is a network of Lean experts dedicated to helping organizations understand and implement Lean Enterprise practices. HLS

Figure 5.4: Harris Lean Systems logo

views Lean Enterprise, originating from the Toyota Production System, as the most effective model for achieving sustainable continuous improvement. HLS works with companies aiming to adopt or tailor the Toyota Production System or develop their own Lean production approach.

- They develop a plan based on mapping the current state and future state value streams (using the Learning to See value stream mapping approach).
- They ensure the transfer of both understanding and implementation skill from us to staff leaders, expecting to see visible change in your operations within a matter of months.
- They do not demand that you commit to placing some of their Lean practitioners in your facilities on a fulltime basis nor do they emphasize, quick hitting kaizen activities. Typically, these kaizen activities are not sustainable. They drive for quick change that is sustainable through a 12-step approach to ensure that the learning is transferred, and the systems are in place.

HLS support in the process was crucial and gave the opportunity to absorb the knowledge of a more than 20 years' experience in improving companies' workflow (Harris Lean System, n.d.).

5.5 Methodology Approach

From an operational perspective, the project was structured as follows:

- Weekly meetings for each of the three workgroups to advance the AS IS analysis and TO BE design in the three focus areas: internal logistics, production process, and quality.

- Monthly alignment meetings with the entire project team to share each group's progress, obtain constructive feedback, and maintain an overall vision.
- Monthly project status updates to Corporate to monitor the model cell's progress, with a focus on the number of kaizen points, productivity, 5S implementation, and ongoing analysis.
- Weekly alignment on the progress plan with the Operations team within the project meeting.
- Monthly two-days confrontations with a Harris Lean Systems consultant to assess what had been made during the month ad shape better the monthly targets.

5.6 Value Stream Map

The eHM line is one of the most productive insides of the Lowara environment, meaning that it is crucial to map its value stream to fully optimize the process.

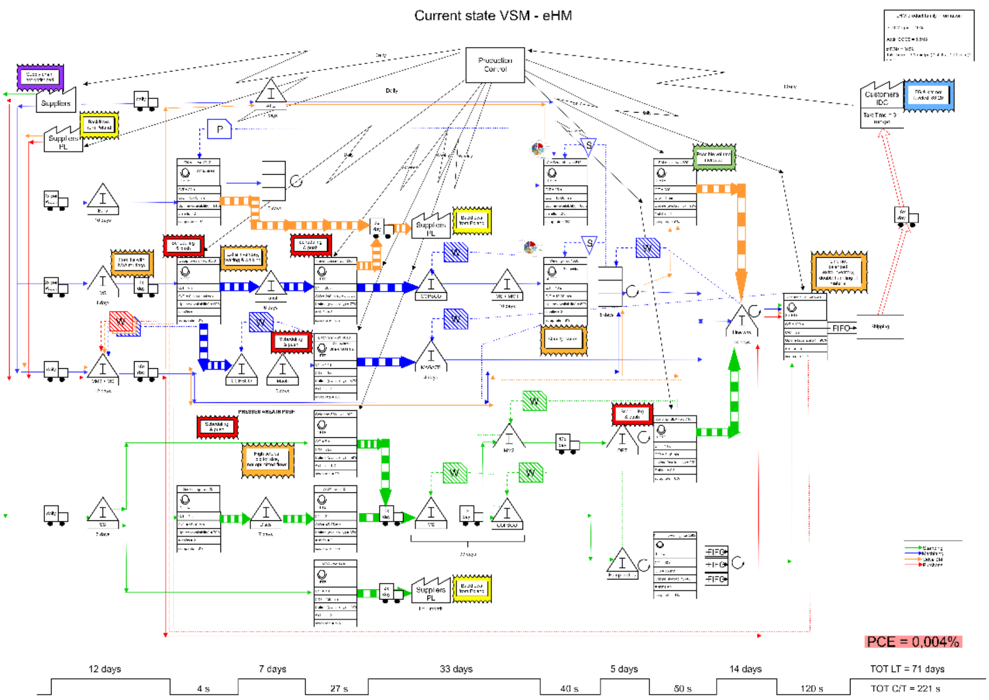


Figure 5.5 Value Stream Map of the e-HM line in the AS IS

The value stream map reveals numerous inefficiencies and waste, with multiple backflows and lead times that are excessively high due to historical factors/outdated practices, complex flows deemed too challenging to analyze, and so on. These issues result in a value stream that is far from lean, leaving significant room for improvement.

Figure 5.5 illustrates several areas within the stream that require improvement. While each area is being addressed, only one will be the focus of this paper: the e-HM assembly line, which has been identified as the pacemaker of the value stream.

5.7 AS IS Configuration

In order to fully understand what needs to be done inside of the line, the AS IS configuration will be now presented, highlighting how it works now and what are the most critical issues.

5.7.1 eHM Assembly Line

The productive environment of Lowara, as said before, is divided into 2 Continuous Flow Units, that are divided into 6 Sub Continuous Flow Units (7 considering Internal Logistic but we are currently analyzing the production environment), and each of this unit is divided into cells that are then divided again into work centers (WC), areas dedicated to the production of a certain number of semi-finished codes or finished products.

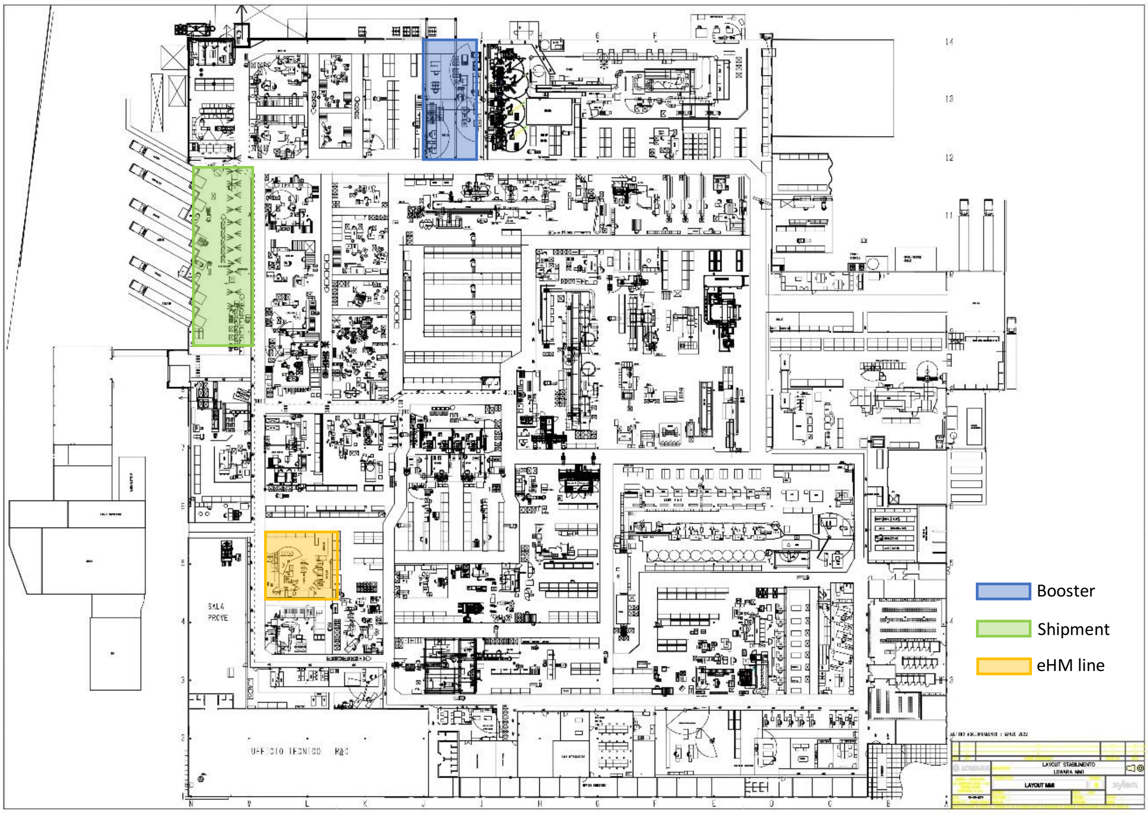


Figure 5.6 e-HM line inside production layout

The eHM assembly line falls in the WC 5320, which is part of the SUBCFU 06 (Figure 5.6). The line output goes to the shipment area or to the Booster area.

Having adopted the lean philosophy to create customer value and align production with actual demand, Xylem selected a mixed-model line configuration with a flexible L- or U-shaped layout, minimizing major losses due to setup activities. For line feeding, they chose a line-stocking approach, with small-sized component containers or boxes placed on designated gravity slides in front of the line operator.

The line operates in both make-to-stock (MTS) mode, to replenish warehouse stock for high-repetition motors, and make-to-order (MTO) mode to fulfil end customer orders or supply sub-assemblies to the assembly lines of pressure groups (SUB CFU 10), which “pull” production from the eHM line. Production orders are planned daily considering the capacity of the line and the availability of materials.

The numbers of operators working inside the line is variable and it is defined daily based on the orders quantity and the operator’s availability (absenteeism).
The line works in two shifts but for good comparison the calculations the follows will be done considering one shift, which is the target of the TO BE configuration.

To make the work less monotonous and prevent muscle strain during the day, operators perform a job rotation every hour, which also brings benefits in terms of polyvalence[8]. Regarding ergonomics, gravity-fed structures and pull-out carts (for pallet positions on the ground and first level) were implemented to ensure all operations on the lines and in the supermarkets are not strenuous. Additionally, in work centers where components over 15 kg are handled, overhead cranes, manipulators, and mobile tables were installed to aid in lifting and moving parts; however, this does not apply to the project's work centers. Finally, all equipment used on the lines, such as screwdrivers, electric and/or hydraulic testing benches, are equipped with safety systems, and it is mandatory to wear personal protective equipment (PPE) depicted in the standard work displays.

[8] Through a polyvalence matrix (or Skills Matrix), competences of the works are traced, to easily know how to fully exploit their characteristics.

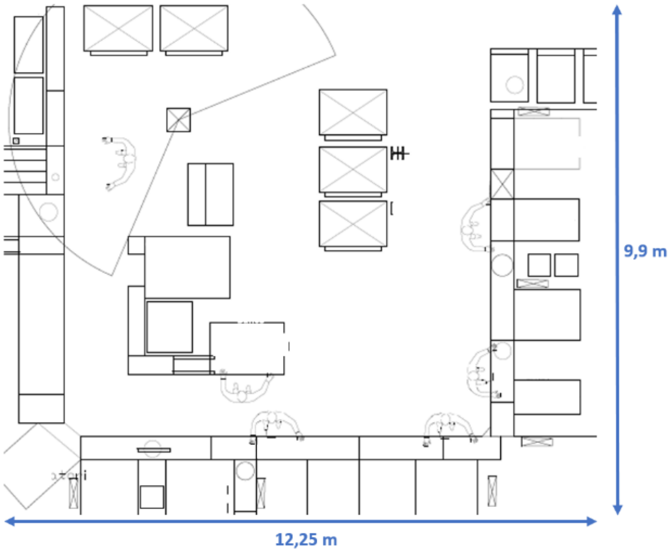


Figure 5.7: Layout AS IS of eHM assembly line

The layout of the line (Figure 5.7) shows how the line right now has a high square footage and a lot of space inside of it.

The line has a U-shape, but the space is not optimized; it includes a rework bench and racks containing extra materials, as well as a hydraulic test station that is positioned in the middle rather than along the line.

As said before, eHM line can produce pumps that are packed and stored/shipped but also pumps that are sent unpacked to the Booster, where they will be assembled into pressure groups.

5.7.2 eHM portfolio of products and their components

The eHM pumps is a horizontal multistage model of pumps and is divided into two main parts: motor and hydraulics (Figure 5.8).

The line currently produces more than 3000 different products, that can be split into four families by their motor size, from biggest to smallest: Mec 80, Mec 71 and Mec 61.

Figure 5.8: e-HM pump

The pump is mainly made of the following components:

- Wounded stator in housing

- Drain plugs
- Compensation ring
- Rotor shaft
- Motor adapter
- Foot or support
- Fan
- Fan cover
- Spacers
- Seal ring
- Pump body
- Impeller
- Diffuser
- Filling plug
- Pump Shaft
- Mechanical Seal
- Seal Housing
- Terminal Box
- Terminal Box Cover
- Electrical parts (capacitors, terminal, etc)

A variation of the standard e-HM pump is the e-HME (Figure 5.9), which has a drive instead of a terminal box. This is the only motor that arrives preassembled at the line.
The motor of the e-HME (SM Drive) is sourced from the SMP line (WC 4761) with all motor components preassembled (Figure 5.10), leaving only the hydraulic parts to be assembled. On the e-HM line, it always arrives with a Mec 71 motor.

Figure 5.9: e-HME pump

Figure 5.10: SM Drive

Another type of motor that arrives preassembled at the line is the UL motor, available in three different sizes. Its distinctive feature is the unique connections inside its terminal box, which differ from the standard plastic box. The motor is initially assembled on the SMP line (WC 4760) and then sent to the UL line, where the terminal box connections are completed. In the end, it is delivered to the assembly lines.

The motor can be designed as either single-phase or three-phase, which changes the components assembled inside the terminal box.

Most of the hydraulic components of the pump are made of stainless steel AISI 304. An AISI 316 version is also available, though it is less common due to its higher cost, as the pump is primarily designed for residential use. For the impellers, plastic versions are also available, and the number of stages (the number of diffusers covering the impellers) can vary. This, in turn, affects the height of the pump body, which increases proportionally with the number of stages.

The suction port diameter of the pump body can vary between 1-1/4", 1", and VICTAULIC (a specialized port type). This information will be relevant later in the discussion.

Figure 5.11 provides an overview of the different pump sets the assembly line can produce, temporarily excluding those classified as "specialties."

Phase	Single-phase	Tri-phase
Size	Mec 63, Mec 71, Mec 80	
Config	Drive, UL	
Impeller	Plastic, A304, A316	
Pump body	A304, A316	

Figure 5.11: e-HM pumps configurations

All the components described above are the ones regarding the actual pump, but when looking at the layout of the line, more components are to be considered, such as:

- Manuals
- Labels
- Packaging
- Screws
- Grease, alcohol, etc

These components are important to consider, as they impact the flow within the line.

It’s also essential to address the "specialties": despite the pump’s relatively simple design, the line has over 3,000 different combinations. This high level of customization, which has been accepted for years, has led to a non-standardized process. Various components and configurations regularly move through the line, disrupting continuous flow and unbalancing the line.

The matrix below (Figure 5.12) shows the different combinations that significantly impact the process, excluding combinations that do not directly affect the process but still require additional components around the line.

	STANDARD				MEC 80					Cliente										LIV 12/13/...	
	MEC 63	MEC 71	MEC 80	eSM DRIVE	UL	RESIBOOST	IMI	KELVIN	DAIKIN	TAPPO + VALVOLA	ELP CON CAVO	GOMITO	DOPPIO PRESSACAVO	MOLLA 002890300	CORPO RUOTATO	VICTAULIC	MULTIPACK	BIANCHI	TENUTA 002231429	NO PACKAGE	COLLAUDO 100%
1 - MOTOR	s	s	+	-	+	s	s	s	+	s	s	s	s	s	s	s	s	s	s	s	s
2 - SHAFT	s	s	s	s	s	s	+	s	s	s	s	s	s	s	s	s	s	s	s	s	s
3 - DPT+SEAL	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	+	s	s
4 - HYDRAULICS	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s
5 - HYDRAULICS	s	s	s	s	s	s	s	s	s	+	s	s	s	s	s	s	s	s	s	s	s
6.1 - TERMINAL BOX	s	s	s	-	+	+	s	s	+	s	+	(+)	s	s	s	s	s	s	s	s	s
6.2 - ELECTRICAL CONNECTIONS	s	s	s	-	-	s	s	s	+	s	s	s	+	+	s	s	s	s	s	s	s
7.1 - ELECTRICAL TEST	s	s	s	+x	s	+	s	s	s	s	x	s	s	s	+	s	s	+	s	s	
7.2 - HYDRAULIC TEST	s	s	s	+	+	s	s	s	s	s	s	s	s	s	s	+	s	s	s	s	+
8 - PACKAGING	s	s	+	+x	s	s	s	s	s	s	s	s	s	s	s	s	-	s	s	-	s

Figure 5.12: Combinations and their impact on the assembly process

5.7.3 Workstations

The finished product has a high number of components as stated before, that is why the assembly line in is divided into 8 workstations (Figure 5.13), each hosting the various steps of the assembly process:

Workstation 1: **Motor**

Workstation 2: **Shaft**

Workstation 3: **Seal housing + seal**

Workstation 4: **Hydraulic Pack**

Workstation 5: **Pump body**

Workstation 6: **Electrical parts**

Workstation 7: **Testing**

Workstation 8: **Closure + Packaging**

The semi-assembled part is the moved among each workstation, until the final one in which it is packaged or sent to the Booster area.

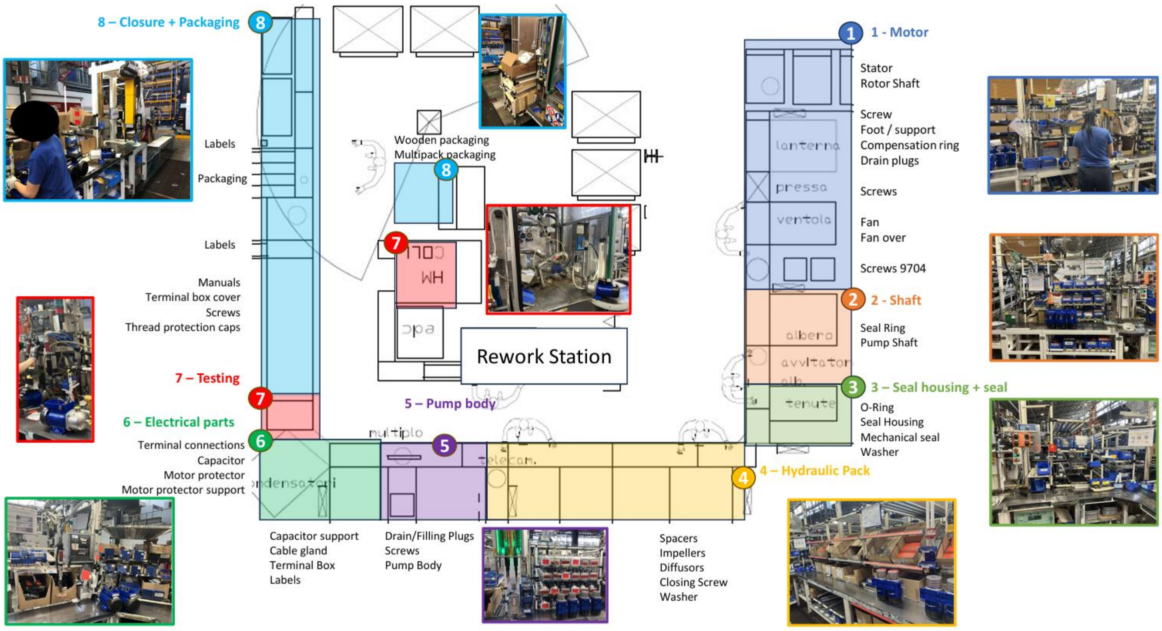


Figure 5.13: Workstations of the assembly line

The amount of people that can work inside the line can go from 3 to 6, and it is determined by the daily number of pumps planned and the availability of the operators (absenteeism).
The number of people working for each shift is determined weekly and it is adjusted daily.

5.7.4 Assembly process

This section provides a detailed look into the structure of the assembly process, describing the micro-phases performed at each workstation.

Workstation 1 is supplied with a kit containing the stator in housing and the rotor shaft, with the rotor shaft positioned inside the stator. These two components are selected and combined by the operator working in the supermarket, who has a copy of the Bill of Materials (BOM).

The kit is delivered to the line on a cart that can hold multiple production orders. The first kit of each order has the BOM placed on top, making it easier for the first operator on the line to identify each batch.

Below is a description of the tasks into which the assembly process is divided:

WORKSTATION 1

1.1 Positioning of motor adapter on pallet.

1.2 Gathering of rotor shaft from stator in housing (while checking the rotor pack height).

1.3 Drain plug insertion.

1.4 Foot Screwing OR Support Hammering (depending on Mec size).

1.5 Positioning of stator on rotor shaft.

1.6 Insertion and check of compensation ring (with the use of an insertion pad for centring it).

1.7 Stator coupling and fan insertion/check.

1.8 Motor case screwing.

1.9 Positioning and screwing of fan cover.

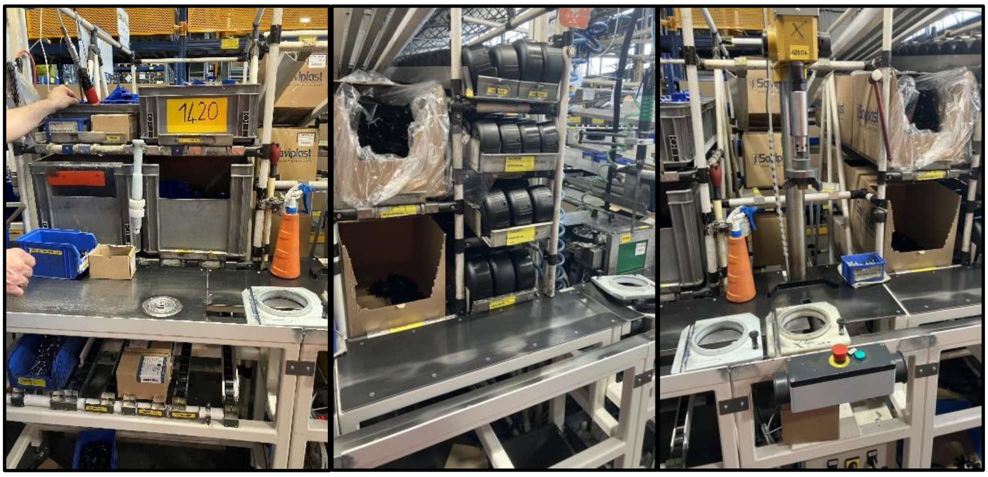


Figure 5.14: Workstation 1 AS IS

WORKSTATION 2

2.1 Positioning and insertion of seal ring.

2.2 Application of Loctite (glue) on rotor shaft thread.

2.3 Screwing of pump shaft.

2.4 Centring check and manual straightening.

Figure 5.15: Workstation 2 AS IS

WORKSTATION 3

3.1 Seal housing assembly, O-Ring insertion (with an insertion pad) and air blowing.

3.2 Insertion of fixed mechanical seal.

3.3 Insertion of rotatory mechanical seal and shoulder washer.

Figure 5.16: Workstation 3 AS IS

WORKSTATION 4

4.1 Assembly of stages.

4.2 Screwing impellers pack.

4.3 Assembly of initial stage.

4.4 Stages pack check with camera.

Figure 5.17: Workstation 4 AS IS

WORKSTATION 5

5.1 Positioning of pump body.

5.2 Screwing of fill/drain plugs.

5.3 Screwing of pump body.

5.4 Mark after screwing check.

Figure 5.18: Workstation 5 AS IS

WORKSTATION 6

6.1 Screwing of cable gland in the terminal box.

6.2 Screwing of terminal box.

6.3 Application of labels on terminal box and fan cover.

6.4 Insertion of capacitor support (single-phase).

6.5 Assembly and positioning of terminal connector (single or mono -phase).

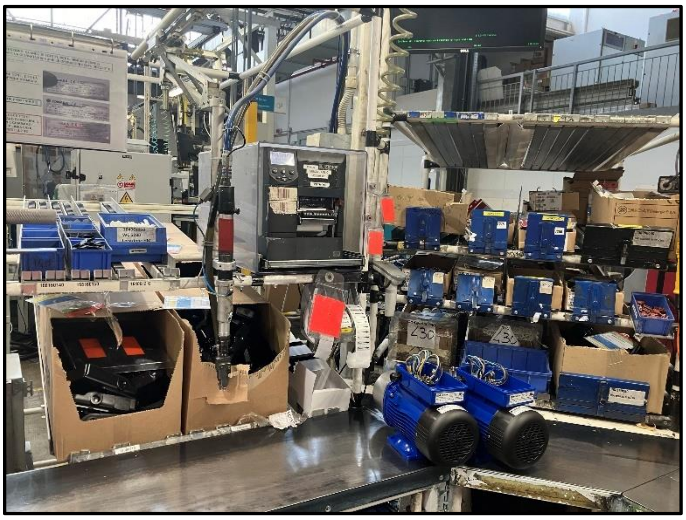


Figure 5.19: Workstation 6 AS IS

WORKSTATION 7

7.1 Static and electric testing.

7.2.1 Setup for hydraulic test (every part number change).

7.2.2 Test conclusion and draining of pump (every part number change).

7.3 Screwing of terminal box cover.

7.4 Insertion of thread protection caps.

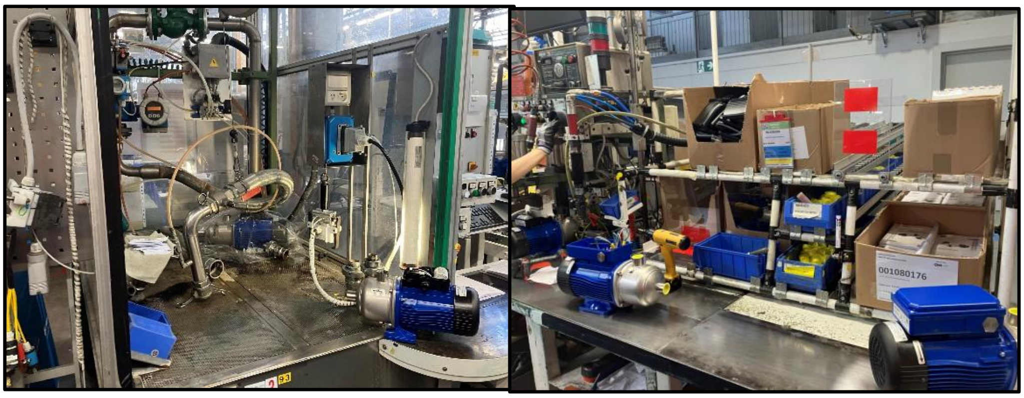


Figure 5.20: Workstation 7 AS IS

WORKSTATION 8

8.1 Application of barcode on manual, stitching of packaging base and insertion of protective sheet.

8.2 Positioning of the pump on cardboard box (for Mec 80 manipulator needed) and closing.

8.3 Allocation of the pump and application of third label

8.4 Palletization

Figure 5.21: Workstation 8 AS IS

5.7.5 Information related to the assembly process

The e-HM line produces daily on average 320 pumps, working on two shifts daily (available time = 14 hours).

The Total Cycle Time is of 454 s, and it took various timing sessions (Table 5.1).

To have a valid data to work on, times have been taken from the assembly of the high-runner type of pump, based on volumes: a 4 stages, single-phase, size Mec 71 pump. For actions that

PHASE	VA	Incidental	NVA
Kit Motore	0	24	0
Posizionamento supporto su tavola	2	2	0
Prelievo albero da statore	2,8	1,2	2,4
Spostamento da supermarket a pressa IMI	0	0	0
Dosaggio loctite su filetto albero motore	2,6	1	0
Avvitatura e fissaggio albero pompa	5	9,4	0
Verificare fuoricentro e rettfiica manuale	19	0	0
Inserimento albero montato su flangia	0	0	0
Spostamento da pressa IMI a supermarket	0	0	0
Inserimento e controllo anello di compensazione	0,6	6	3
Posizionamento e inserimento anello tenuta	1	5	4,8
Prelievo cassa motore e posizionamento per inserimento anello di compensazione	0	0	0
Posizionamento cassa motore	1,6	0	6
Spostamento da smkt a linea	0	0	0
Assemblaggio cassa e inserimento+check ventola	4	8	0
Avvitatura cassa motore	6	6	6
Inserimento e avvitatura copri-ventola	4	6,8	0
Inserimento tappi di scarico condensa	4	5,6	1,2
Fissaggio piede di sostegno	8	2,4	0
Avvitatura pressacavo scatola morsettiera	1,8	3	0
Avvitatura scatola morsettiera	4	3,6	0
Assemblaggio discoportatenuta, inserimento OR e soffiatura	5,16	6	4,8
Assemblaggio tenuta fissa	2,8	2	0
Assemblaggio tenuta rotante e rondella di spallamento	3,4	5	0
Assemblaggio stadi	10,8	4	8
Bloccaggio pacco girante	6,96	3	2,4
Assemblaggio scatola stadio iniziale	0,6	0,6	0
Verifica pacco con telecamera	4	0	0
Posizionamento corpo pompa	0,6	1,8	4,8
Avvitatura corpo pompa	18	14,76	0
Marcatura avvenuto serraggio	0	0	4,8
Avvitatura tappi carico/scarico	8,92	5	0
Installazione staffa ferma condensatore	1	1	1
Assemblaggio e inserimento morsettiera monofase	15	6	0
Applicazione etichette scatola morsettiera e copriventola	2,4	4,32	0
Collaudo elettrico e di tenuta	6	7,2	0
Avviamento collaudo idraulico	3,5	1,3	1,1
Conclusione collaudo (svuotamento)	0	2	0
Avvitatura coperchio scatola morsettiera	6	4,8	0
Applicazione tappi salvafiletto	2	4	0
Applicazione codice a barre scatola e libretto, graffettatura fondo e inserimento carta protettiva	21	12	9,6
Alloggiamento pompa e chiusura imballo	11,6	10	0
Versamento pompa e applicazione 3a targa	1,2	3	3
Pallettizzazione	4	8	0
	201	**190**	**63**
		454	

Table 5.1: Times Observations

are strictly related to a single-phase pump, times have been proportionally adjusted. The time of the hydraulic test have been divided by 9 because the average daily number of tests is 35, and 320 pumps a day divided by 31 tests gave us a frequency of 1 test every 9 pumps.

The takt time with the AS IS configuration is then calculated as:

$$takt\ time_{AS\ IS\ (2\ shifts)} = \frac{840\ min/d}{320\ pcs/d} = 2.63\ min/pc = 158\ s/pc$$

And the line can work at this rhythm by employing 3 operators per shift (Figure 5.22):

$$n°\ of\ operators_{AS\ IS\ (2\ shifts)} = \frac{454\ s/p}{158\ s/p} = 2{,}9\ operators = 3\ operators$$

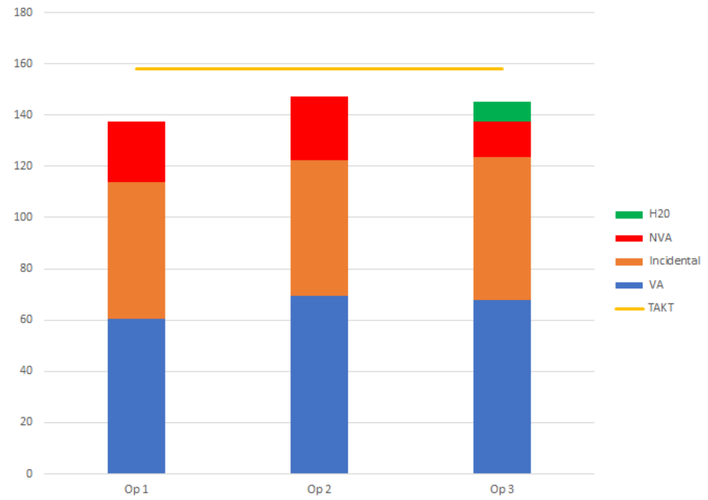


Figure 5.22: Operator Balance Chart AS IS (2 shifts)

The target of this lean transformation process is also to get to work on 1 shift, so for good comparison, a calculation of the takt time with the AS IS configuration will be done considering working on a 1 shift daily

$$takt\ time_{AS\ IS\ (1\ shifts)} = \frac{450\ min/d}{320\ pcs/d} = 1{,}41\ min/pc = 85\ s/pc$$

The line can work at this rhythm by employing 5 operators per day (Figure 5.23):

$$n° \; of \; operators_{AS\,IS\,(1\,shifts)} = \frac{450\; s/p}{85\; s/p} = 5{,}3 \; operators = 5 \; operators$$

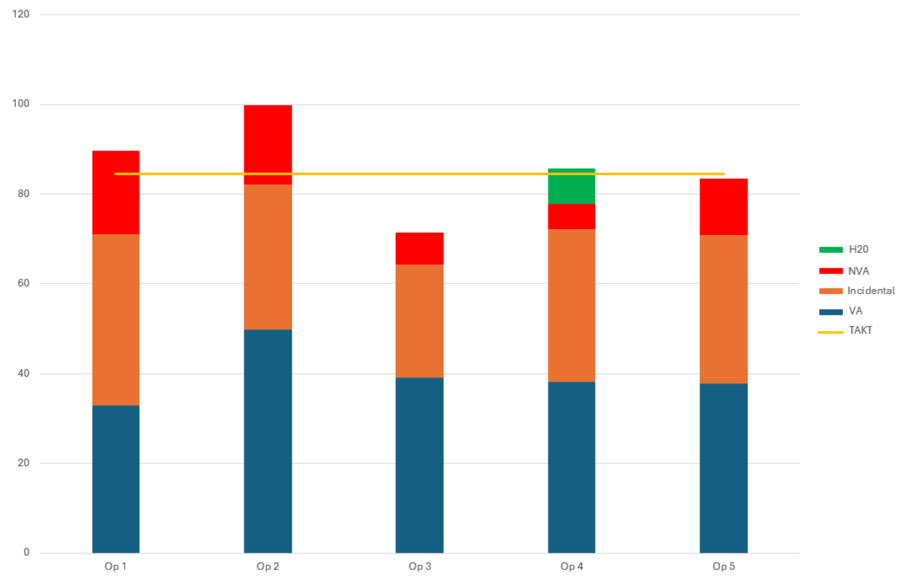


Figure 5.23: Operator Balance Chart AS IS (1 shift)

The scheduling of the line is based on a classification assigned to each finished product's part number, known as the technical sequence. The technical sequence is a series of 4 to 6 digits used to create a hierarchy in pump classifications. Each technical sequence falls within a four-digit series, which also includes an Assigned Time.

This classification helps the Production Planner assess whether the production volume aligns with the line's capacity. On the e-HM line, the technical sequence is primarily used to quickly identify specific characteristics of each pump:

- Impeller material
- Motor size
- Destination (shipping or internal use)
- Single-phase or tri-phase

Most of the work is left to the production planner and to the line itself, that now has lot of non-standard activities and wastes which handles improvising DIY combinations of production orders.

5.7.6 NVA activities

As is evident from the layout of the line, its square footage is not fully optimized, with much of the space underutilized. The main issue can be traced back to one key factor: customization.

Over the years, various combinations of the product have been added to the portfolio without fully considering how to maintain alignment with the standard. As a result, the line has become longer than necessary—sometimes due to volume, and other times because of material lead times—simply because different variations of the same components need to be presented to the operator.

The analysis of the timed process revealed that most of the non-value-added activities are related to motion and transportation. The incidental value-added activities stem from the fact that the process has not evolved at the same pace as the product. This has resulted in structures that are not optimally designed to accommodate materials efficiently (see Figure 5.24, Figure 5.25).

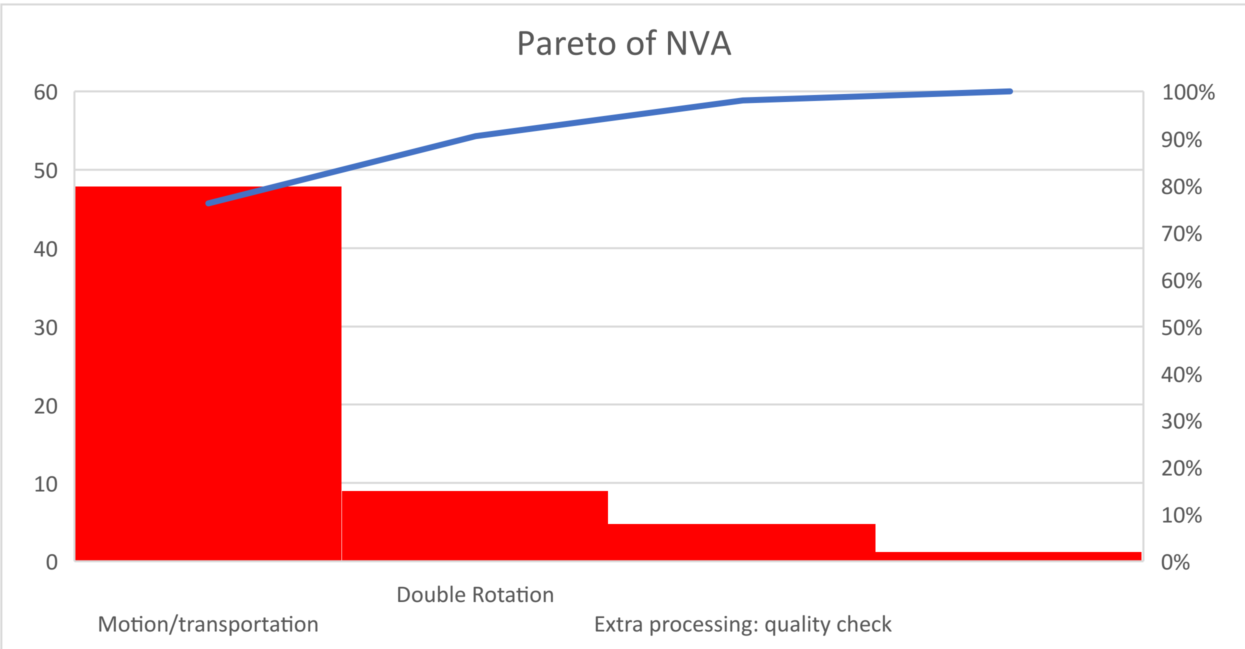


Figure 5.24 Pareto of NVA

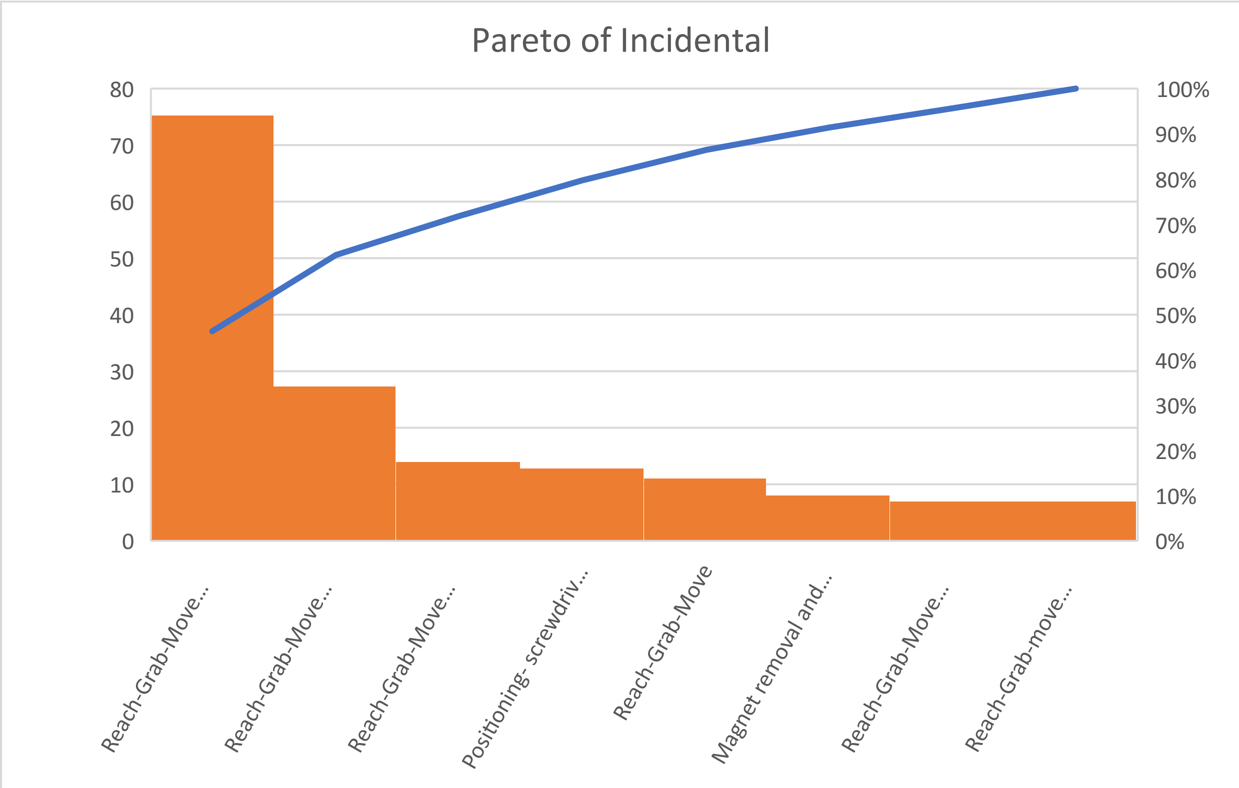


Figure 5.25: Pareto of Incidental activities

5.7.7 Material presentation and specialties

In the AS IS configuration, the size of the assembly line is largely influenced by the volume of materials presented to the operator.

The hydraulic workstation occupies the most space, with up to 3 meters of various impellers, diffusers, initial stages, and other components made of different materials (A304, A316, plastic) and in different sizes (1, 3, 5). Any components not stored on racks beside the line are placed on standalone racks or on the rework station, which primarily serves as a table for special components.

Most components that have dedicated racks also have designated locations in the supermarket. The supermarket is an area above the assembly line where components are stocked and brought to the line by the "water spider." The water spider is the operator responsible for three key tasks: kitting the carts with the correct components, ensuring the correct specialties are provided, and feeding the line as needed.

Not all components are moved from the supermarket to the line; some are supplied directly to the line by internal logistics. This is primarily the case for purchased goods and not WIP (Work in Progress) components.

Every component with a dedicated rack on the line operates under a kanban system.

Beyond the large quantity of materials in the line, the issue is the number of specialties brought in daily. Currently, specialties such as mechanical seals, O-rings, and others are placed on the rework bench or brought to the line on supplementary carts (e.g., feet, motor adapters, cables). This is possible because the line still has a significant amount of space. However, this method does not align with the continuous flow principle and leaves too much room for errors.

5.7.8 Critical Workstations

The issues of the line previously described are located on all the workstations, it is needed to go deeper into some of the stations, which have high impact on the flow inside the line

- Hydraulic Test

One significant issue with the line, which currently does not cause a major bottleneck, is the hydraulic test.

In the AS IS configuration, the hydraulic test is positioned in the middle of the line, with a lot of space around it in case of any issues. This setup means that when a pump reaches the test stage, operators must perform unnecessary motions, as the test is not integrated into the line itself.

The reasons why the hydraulic test is not currently located on the line side are as follows:

- Testing Protocol: The hydraulic test is not conducted on every pump but rather every time there is a change of part number, and every 30 consecutive pumps with the same part number. This creates a scenario where, for example, if one batch has a part number of 1 and the next batch also has a part number of 1, two consecutive tests are required. This is not sustainable in a continuous flow process due to both the machine time and labor involved in performing the test.
- Time: The overall cycle time for the hydraulic test is 2.7 minutes—half of which is spent preparing and draining the pump (70.8 seconds), and the other half is machine time (94 seconds). This makes the test a natural bottleneck, especially when dealing with a takt time of 85 seconds.

A major issue that exacerbates the hydraulic test bottleneck is the frequency of NO GO results. When this occurs, it halts the flow, forcing the operator at the head of the line to leave their workstation, take the NO GO pump, and often disassemble it. This process can be repeated multiple times, eventually leading to a misuse of the test settings.

These challenges need to be addressed using the A3 problem-solving methodology.

The A3 started from observations made during April 2024 on the results of the hydraulic tests.

The problem statement is:

"*During a study carried out on April 2024 on the hydraulic tests performed in the eHM line of MM, it emerged that on average 40 tests are performed every day, and a considerable part of them resulted on a NO GO result.*

Both the frequency of the test and the percentage of NOGO lead to an imbalance in the line and consequent loss of productivity."

To make the data more robust, the proportion between the GO and NO GO from January 2024 to April 2024 have been extracted (Figure 5.26)

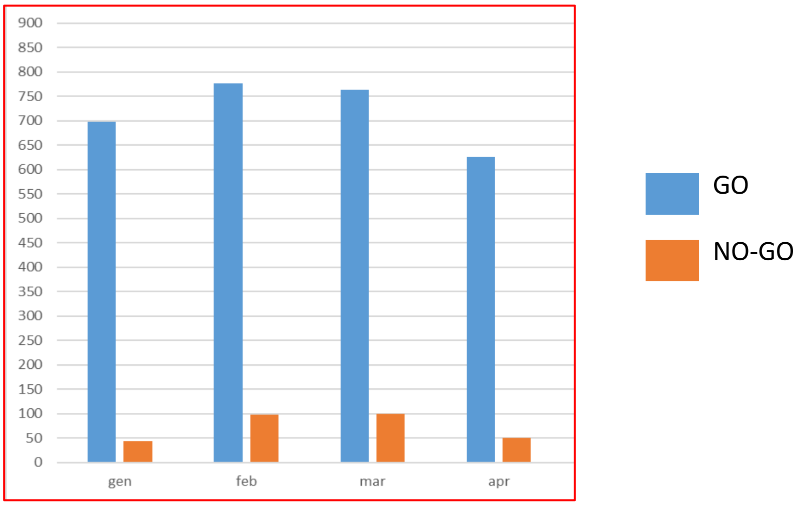


Figure 5.26: GO and NO GO results from January 2024 to April 2024

The resulting proportion is of 90% Go and 10% NO GO per month, meaning that out of 6400 pumps made, 640 of them are rejected from the test and then reworked.

In order to properly identify causes, the Ishikawa diagram was used, both for the frequency and the percentage of NOGO (Figure 5.27)

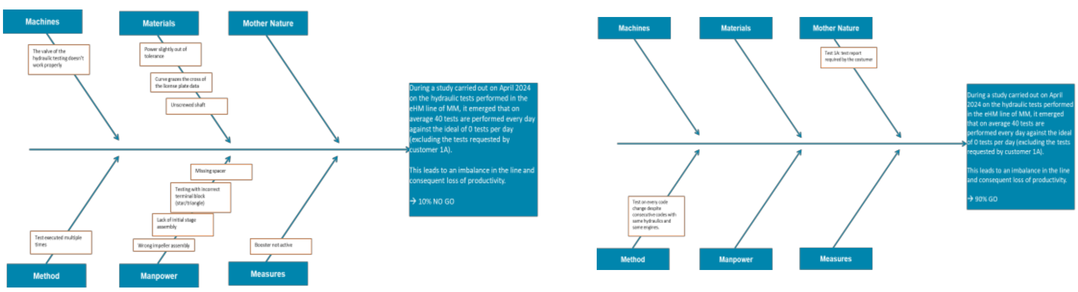


Figure 5.27: Ishikawa diagrams of frequency of test and their

After having identified all the root causes, the root causes need to be identified using 5Whys methodology (Figure 5.28).

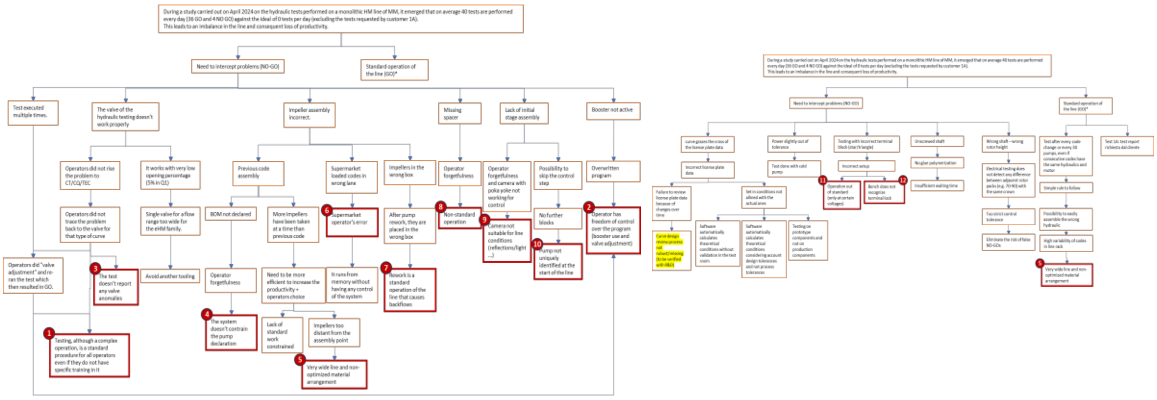


Figure 5.28: Root Causes

Being the hydraulic test one of the focal point, countermeasures need to be planned in order to

eliminate the causes, while putting them also on a Benefit/Effort matrix (Figure 5.29)

Nr	Root cause	Countermeasure
1	Testing, although a complex operation, is a standard procedure for all operators even if they do not have specific training in it	Make the testing phase a special process
2	Operator has freedom of control over the program (booster use and valve adjustment)	Limit the program setup operations for testing to a few authorized, experienced individuals
3	The test doesn't report any valve anomalies	Automatic alert for valve anomalies
4	The system doesn't constrain the pump decaration	Restrict the pump declaration in the hydraulic assembly
5	Very wide line and non-optimized material arrangement	Relayout the line and cart for homogeneous families of hydraulics
6	Supermarket operator's error	Conduct hydraulic testing after every impeller box change to detect any feed errors
7	Rework is a standard operation of the line that causes backflows	Have repairs performed off the line by dedicated/experienced personnel (recording pump-serial number repaired)
8	Non-standard operation (spacer)	TBD
9	Camera not suitable for line conditions (reflections/light...)	Technology change (camera)
10	Pump not uniquely identified at the start of the line	Implement unique identification of pumps at the beginning of the line
11	Operation out of standard (only at certain voltages)	TBD
12	Bench does not recognize terminal lock	TBD

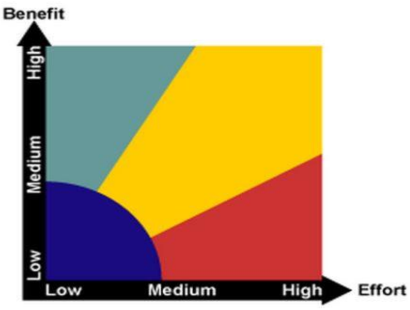


Figure 5.29: Countermeasures and Benefit/Effort matrix

- <u>Pump body</u>

A significant issue with the line setup concerns the feeding process for the pump bodies. While the process meets the line's immediate needs, it requires excessive inventory space and includes a double-handling phase, which is wasteful.

Currently, pump bodies without nozzles (intake and outtake) are transported from the WCP press to the welding station. At the welding station, the operator attaches the inlets, then places a specific quantity of pump bodies into labelled boxes, which are subsequently loaded onto a rack.

From the opposite side of the rack, the water spider operator collects these boxes and transports them to the assembly line. Once at the line, the boxes are unloaded onto a rack with single lanes for each part number, allowing operators to pick up pump bodies individually and slide them down roller lanes.
The welding operators follow a "full-to-empty" workflow, only welding the boxes that the water spider has returned completely empty. To minimize frequent setup changes, operators create a buffer by stacking empty boxes on the floor until enough accumulate.

This process consumes excessive space and increases handling steps, which ultimately limits efficiency and disrupts flow on the line.

The setup is dictated by the type of nozzle, which can be:

- 1’
- 1’ ¼
- VICTAULIC

The first two are the most common, the last one is still considered a speciality due to their volumes.

Setups in this station is:

- 15 minutes when going from a 1’ to a 1’ 1/4 and vice versa
- 30 minutes when going from a VICTAULIC and vice versa

- Screwing station

This station is the first station that starts working on the hydraulic part of the pump since the beginning of the process.
In this station three main phases are performed:

1. Pouring of glue inside the thread of the rotor shaft
2. Screwing the pump shaft into the rotor shaft with a screwing machine the aligns the pump
3. Checking of the shaft alignment with a comparator, if not manually straightening of the shaft with a lever

The process is the most unbalancing aspect of the line for several reasons:

- Glue Polymerization Variability: The glue does not always polymerize at the same speed due to environmental conditions or movement during other steps of the process. As a result, even if the shaft is straightened correctly, misalignment can occur by the time the pump reaches the tests, leading to a NO GO result.

- Screwing Machine Inconsistency: The screwing machine does not always perform with the same timing. In some cases, defects can create excessive gaps between the two shafts, causing them to grip each other incorrectly. When this happens, both components must be discarded.
- Manual Straightening Time: While manual straightening can be skipped if the pump shaft is already straight, it can take up to 8-10 minutes in some cases. Currently, this is manageable because there are fewer people working over a larger area, with buffers of pumps positioned alongside the line. However, this variability cannot remain within the line as it currently exists.

This process unbalancing issue in the AS IS configuration affects all other operators on the line. The buffers created by the line's length help mitigate the impact, but they also lead to unnecessary motion and inefficiency.

5.7.9 Spaghetti Chart

As discussed in the previous sections, there is excessive motion within the line, with many movements being repetitive and unnecessary. Components are scattered throughout the line rather than being strategically placed for easy access by the operator, which leads to exaggerated movements.

Additionally, the high availability of materials increases the risk of errors. The large number of non-standard components, many of which lack dedicated storage locations, results in boxes being haphazardly piled with paper sheets on top.

Rework phases are primarily triggered by NO GO results from both the hydraulic and electrical tests. The analysis reveals that most of these issues are linked to assembly errors and pump shaft misalignment, which is often caused by imprecise manual straightening.

To provide a clearer visualization of the flow within the line, the spaghetti chart of the AS IS configuration is presented in Figure 5.30.

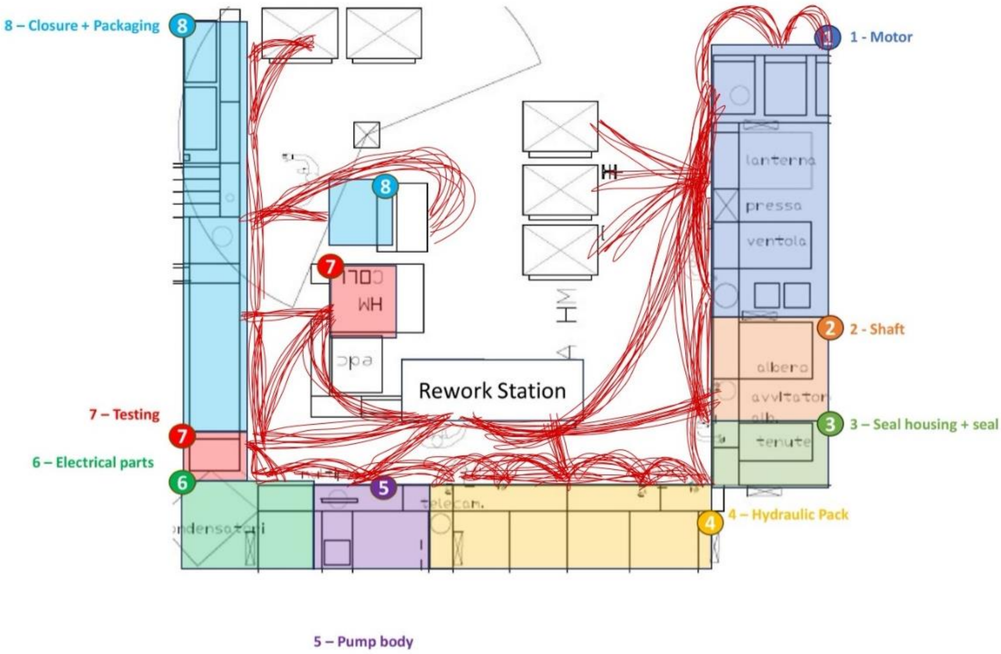


Figure 5.30: Spaghetti Chart of the AS IS

5.8 5S initial score and considerations

The 5S score of the e-HM line in the AS IS configuration has been determined with a 5s audit. The score is made of 5 steps, each step has 5 questions that need to be addressed. If the answer to the question is 100% yes, then the question will give 1 point to the step, otherwise 0 will be assigned to that question.

The sum of the scores of the 5 questions gives the score for the relative step. Xylem chose the philosophy of assigning 0 to all the consequents steps if the scores of the step that is being question is not 5.

In the end, the average of the score of the five steps will give the final 5S score.

In our case, the e-HM line had an initial score of 0,8 dated 25/06/2024 (Table 5.2).

That is because the first step (Sort) achieved a score of only four points, leading to an assignment of 0 to all the other steps.

All the characteristics and issues presented above fully explain the reasons why the AS IS score is low, confirming that actions are needed.

Sort	4
Straighten	0
Shine	0
Standardize	0
Sustain	0
Total	0.8

Table 5.2: 5S score of AS IS configuration

5.9 Conclusions

The proposed chapter examines the current and AS-IS condition of the eHM assembly line. Through Value Stream Mapping, spaghetti diagrams, etc., it identifies some gaps in layout design, amount of material moved in excessive distances, and imbalanced workloads.

These findings signify key areas for improvement, which also serves as the basis on which the lean relayout would be proposed.

Chapter 6

Case Study: TO BE and Expectations

This chapter will present the TO BE configuration of the e-HM assembly line, which is the output of the analysis of the AS IS configuration in chapter 5.

The expectations from the changes made will be presented in terms of savings and improvement of flow.

6.1 Value Stream Map

For good comparison with the value stream map of the AS IS configuration, the TO BE version has been drawn up to be more clear which ones are the goal to be achieved (Figure 6.1).

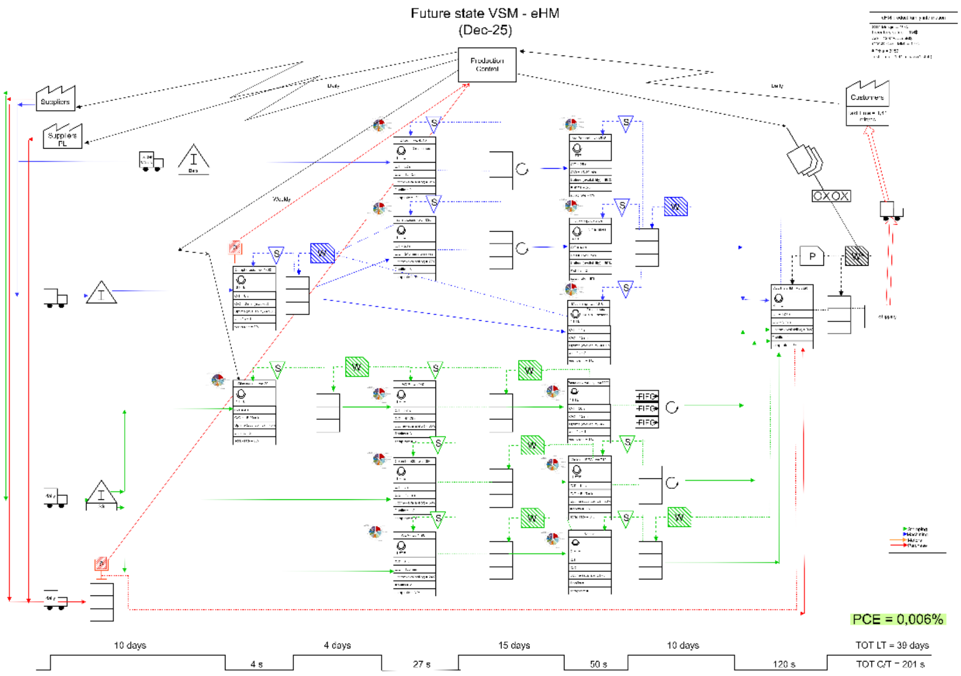


Figure 6.1: Future State Value Stream Map of the e-HM line

The aim of the project is to have everything included in the Future State value stream map up and running by December 2025.

Most of the kaizen bursts presented in the map are not part of what this project is about and will eventually take place with different timings but with the same deadline.

6.2 Kaizen bursts

All the modifications made to the line, in terms phases to be performed in each station, material presentation and time observations will be described in the next paragraphs, keeping track and highlighting the difference between the AS IS and the TO BE configurations.

6.2.1 Supermarket and tugger

The current method for bringing components to the assembly lines involves utilizing supermarkets located near the lines, each dedicated to specific components. These components are brought to the various supermarkets by internal logistics, sourcing materials from both the production area supermarkets within the production area (MM1) and the external warehouse (MM2), where purchased products are stocked upon arrival.

The new logic that Xylem aims to implement is to eliminate the multiple supermarkets for internally produced components near the assembly lines. Instead, they will create properly dimensioned supermarkets near the production areas, where all components produced by the machines in that area will be stored.

This change will free up space within the assembly line area, allowing for a more agile line layout with all lines facing the shipment area. The materials will be delivered by a tugger train that will follow a specific route, enabling the operator driving the train to feed the line directly to the racks, without having to store components in a WIP supermarket.

This new system will reduce and modify the work content of the "water spider" in the AS IS configuration, freeing up space and minimizing the number of people walking around the lines.

The tugger train will return to the line every hour, and the racks inside the line will be sized to hold two hours' worth of materials, plus one additional box. The two-hour buffer ensures the line does not run out of materials in case a cycle is missed. If this happens, the sequence will need to be adjusted, but the line will not stop entirely.

The "plus one box" is necessary because the kanban card will be sent out when the operator opens a new box of components, not when the box is empty. If the operator does not empty the box and starts using another component, additional space for the next box will be required.

To better understand the components used per pump, their frequency, and their location, an analysis of all Level 1 components from the Bill of Materials (BOM) for the eHM pumps was conducted (Figure 6.2). This analysis enabled the creation of the Point of Use Plan For Every Part (POU PFEP, Figure 6.3).

The Point of Use PFEP (Plan for Every Part) was essential for correctly assigning each component to its workstation, determining whether a dedicated lane was needed or if it could be sequenced on a common line.

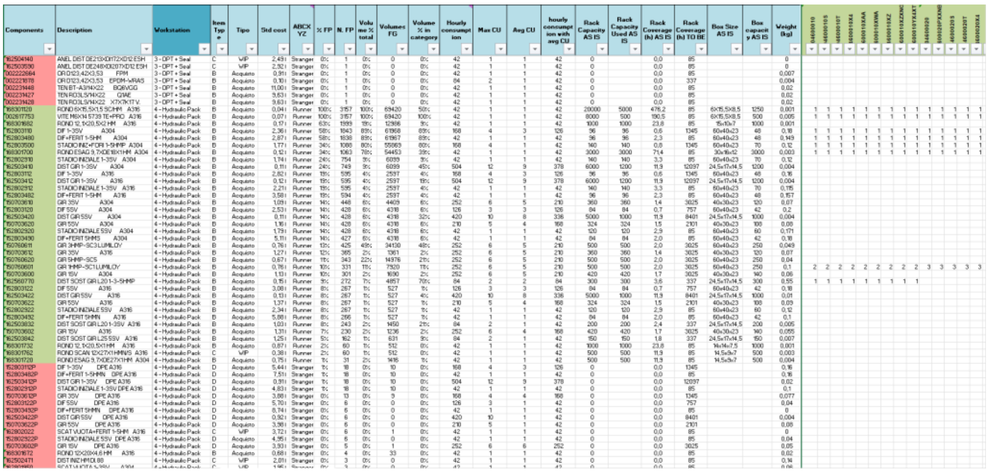


Figure 6.2: Liv 1 components analysis

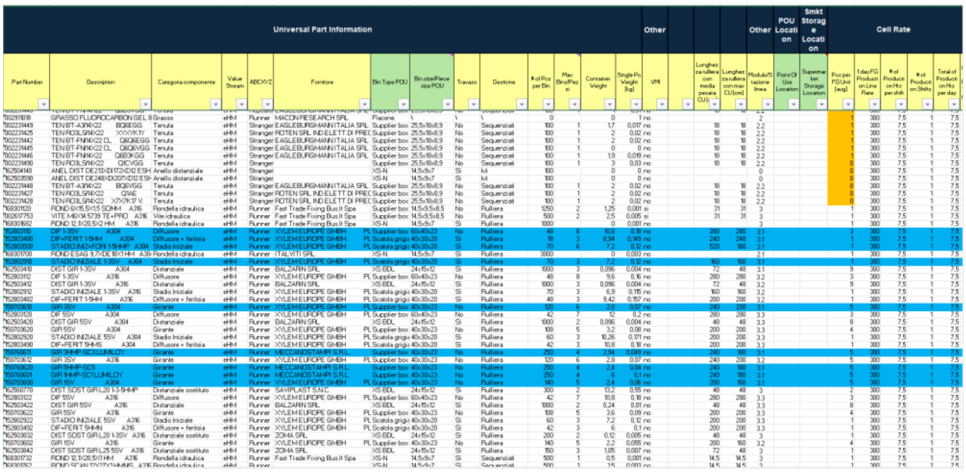


Figure 6.3: Point Of Use Plan For Every Part

6.2.2 Workstation 0: Kitting Isle

During the analysis of the kitting phase in the AS IS configuration, it emerged the fact that the process was simple but ineffective:

1. The stator that is store in the supermarket used to be tuned upside down when putting it on the kart, this action was then repeated inside the line without adding any value, and with bigger sizes (Mec 80) this action created a discrete amount of time loss.
   All these motions lack ergonomics.
2. The rotor shaft used to be picked from its container in the supermarket, put inside the stator, brought to the supermarket, and then again taken out and placed on the motor adapter. This one was also a waste motion.

Figure 6.4: Kit presentation AS IS

From these observations and after looking inside the line, the new kitting process will be now presented.
A new isle outside of the line (Figure 6.4) will be implemented, studied so that in the future will be moved and located in between the two HM line, feeding them both.

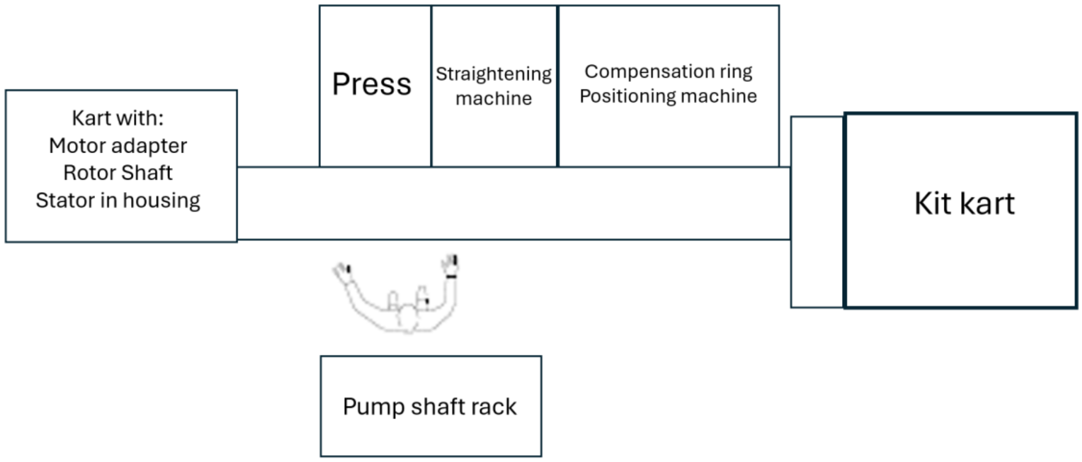


Figure 6.5: New kitting station isle

The new kitting process will then have the following steps:

1. The tugger will bring the components for the new kitting process:
   a. Stator in housing
   b. Rotor shaft
   c. Motor Adapter

   These components will be brought by the train already ordered based on the technical sequence, and presented in the isle in a way that the operator can easily access them and just pull them along the new isle.

   The components will be put on a shaped pallet that keeps the components easily accessible and at the same time divide, to not affect the sequence.
2. The isle will have three machines:
   a. Pump Shaft Press
   b. Straightening Station
   c. Compensation ring positioner

   There will be a rack with all the pump shafts available and the pallets for the final kit.

   When the kart with the sequenced components arrives to the isle, the operator will:
3. Take the pallet and put the motor adapter on it
4. Take the pump shaft and the rotor shaft, position them in the press and insert the first one inside the second one. No glue needed.

   This new press should also reduce the variability induced by the straightening procedure.
5. Take the pump + rotor shaft and check if straightening is needed, if not put it inside the motor adapter located on the pallet, with the pump shaft facing down.
6. Take the compensation ring and position it on top of the insertion pad, which is above the working bench level.

7. Take the stator in housing, positioning it on top of a hole where, by pressing a button, the insertion pad will come up and position the compensation ring inside the stator.
8. Activate the other machine that will position on top of the stator, take him from the side and elevate it. The machine will have a magnet inside that keeps the ring in the right position when the pad will be removed.

   The machine will then move the stator on top of the semi assembled kit, slowly releasing it for a correct insertion.
9. Insert a screw on one of the three holes the connect the stator with the motor adapter, to avoid the rotator to rotate when it is finally positioned.
10. Hammer in the drain plug sing an insertion pad that gives a bigger surface to hammer on. (The plug is about half a centimeter wide)
11. Deactivate the machine that will leave the stator rightfully positioned.
12. Push the kit on a kart made of four channels with rollers that will make the pallet move easily and in the right sequence.
13. Once the kart is completed (20 kits), take the kart and bring it to the line, taking the empty one left from the operator of the line.
14. Come back to the station and start again.

Figure 6.6: Universal pallet for material presentation from tugger

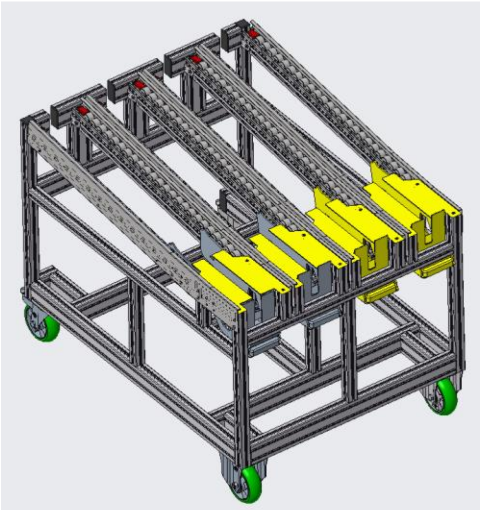


Figure 6.7: New Kitting Kart

Figure 6.7A: New Universal Pallet for Kit in line use

This new kitting methodology, exploiting the synergy with the tugger, will bring order to how the components are presented to the line, reducing mistakes to the minimum and taking out of the line the variability of the straightening procedure.

A focus into the straightening procedure needs to be done: it is a procedure that inside of the line can unbalance all the other operators in the line, by putting it outside it affects only the operator working in the kitting station.

That is because the estimated timing of this process is lower than the cycle time of the line, leaving space for variability.

6.2.3 Workstation 1: Motor

The kitted components are brought to the line in a kart and attached to the first section of the assembly line, which features a roller surface to easily move the kits on the pallets. The kart has three "gates" that allow the first operator to efficiently identify the correct sequence. By opening the gate, the kits (which are slightly sloped) will slide down to the bench, where they can be pushed inside the workstation.

Substantial changes have been made to both the material presentation and process steps at this station:

- Material presentation

  Some components have been relocated outside the line (e.g., motor adapter, compensation ring), and a new phase has been added to this station. Additional racks for specialties have been incorporated so that the tugger will have a dedicated spot to place the components in the correct sequence when needed.

- Process steps

Here also changes in the process have been made:

1. Stator and Motor Adapter Assembly: The stator is now delivered ready to be coupled with the motor adapter. This operation can be done simultaneously while inserting the fan, because the here located press can do both at the same time. By modifying the press and adjusting one of the screwdrivers, the stator can be screwed into place while being held together with the motor adapter. The station will also feature a rotating surface, allowing the screwdriver to remain in the same position, while the semi-assembled motor is rotated so that the operator can easily use the screwdriver.

2. Foot and Terminal Box Assembly: Previously, the screwing of both the foot and the terminal box was done in separate workstations, each one using a manual screwdriver. Since these screws are identical, it was decided to combine the tasks into a single workstation, using one screwdriver that operates horizontally. This eliminates the need for multiple screwdrivers and helps simplify the operator's task.

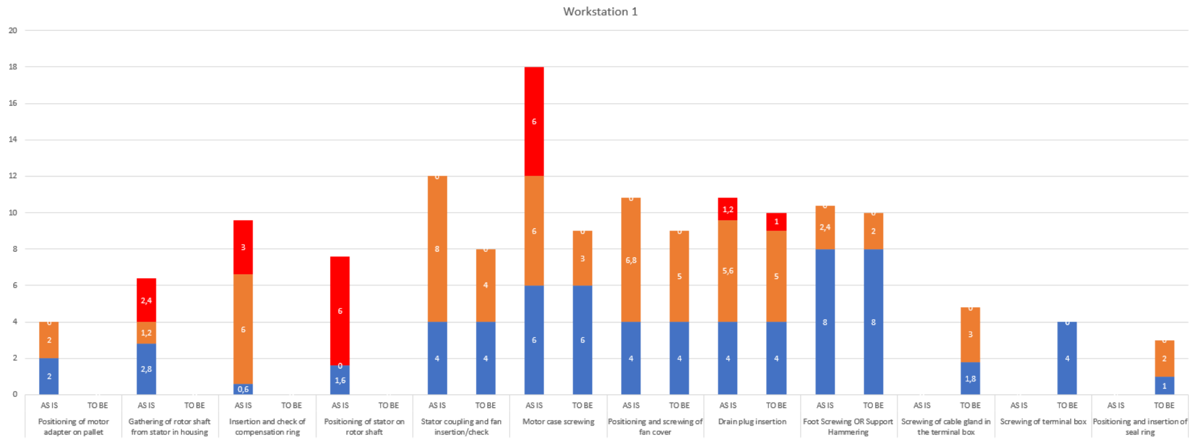
   However, this posed a challenge due to gravity. In the old process, both components were screwed onto the motor case while it was laid horizontally, allowing gravity to assist in positioning the components. To address this, the pallets have been redesigned with shaped parts that support the components while the operator is screwing them in place.

   Another challenge was the working height for taller operators, who may experience discomfort in a position beneath their limbs. This has been addressed by implementing a rotating base for the bench, allowing the screwing area to be adjusted vertically to suit the operator's height.

3. Motor Rotation and Support Installation: After the motor is fully assembled, it needs to be rotated 180° on its vertical axis. This is achieved using a mechanism that locks the pallet in place, while the other part of the motor is inserted onto another pallet and rotated. During the intermediate phase, when the motor is in a horizontal position, the operator hammers in the support (Mec 63 - Mec 71), then completes the rotation.

The unused pallets are pushed onto a dedicated line in front of the operator, allowing the kitting station operator to easily retrieve them.

All the actions put together lead to improvements in terms of flow, ergonomics, and reduction of NVA/Incidental activities (Figure 6.7, Table 6.1).



Δ VA	-2	Δ VA	-2,8	Δ VA	-0,6	Δ VA	-1,6	Δ VA	0	Δ VA	0	Δ VA	0	Δ VA	0	Δ VA	0	Δ VA	1,8	Δ VA	4	Δ VA	1
Δ INC	-2	Δ INC	-1,2	Δ INC	-6	Δ INC	0	Δ INC	-4	Δ INC	-3	Δ INC	-1,8	Δ INC	-0,6	Δ INC	-0,4	Δ INC	3	Δ INC	0	Δ INC	2
Δ NVA	0	Δ NVA	-2,4	Δ NVA	-3	Δ NVA	-6	Δ NVA	0	Δ NVA	-6	Δ NVA	0	Δ NVA	-0,2	Δ NVA	0	Δ NVA	0	Δ NVA	0	Δ NVA	0

Figure 6.8: VA, Incidental and NVA comparison AS IS vs TO BE Workstation 1

Phase Description	Action
Positioning of motor adapter on pallet	**Phase moved to Kitting station**
Gathering of rotor shaft from stator in housing	**Phase moved to Kitting station**
Insertion and check of compensation ring	**Handling of the motor reduced**
Positioning of stator on rotor shaft	**Handling of the motor reduced**
Stator coupling and fan insertion/check	**Handling of the motor reduced**
Motor case screwing	**Handling of the motor reduced**
Positioning and screwing of fan cover	**Line length reduced**
Drain plug insertion	**Handling of the motor reduced**
Foot Screwing OR Support Hammering	**Shared screwdriver implemented**
Screwing of cable gland in the terminal box	**Moved to phase 1**
Screwing of terminal box	**Shared screwdriver implemented**
Positioning and insertion of seal ring	**Line length reduced**

Table 6.1: Improvements per sub-phase workstation 1

6.2.4 Workstation 2: Seal Housing + Seal

This station did not have changes in terms of process, which is because here the process is simple.

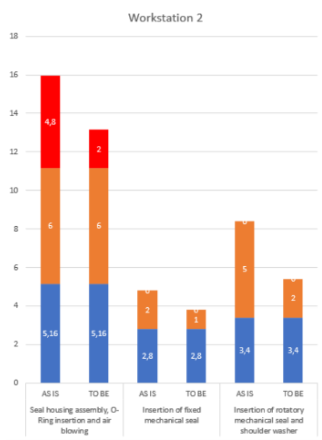
The problem here was mainly material presentation, specifically about the mechanical seals. There are fourteen different types of mechanical seals, and they need to stay of their box, otherwise dust can get inside the tiny sealing parts that make the mechanical seal, causing a fail when testing.

As for now only one type of this component has a dedicated rack in the line, all the others are just placed on top of the rework bench. This stands also for the other components of this station.

A new rack has been designed, giving space for three extra lanes, two for two kinds that are high runner, and one for the specialties, which will be used as explained in the workstation 1. This station did not undergo significant process changes, as the existing process is relatively simple.
There are fourteen different types of mechanical seals, and it is crucial that they remain in their original packaging. If removed from their boxes, dust can contaminate the delicate sealing parts, leading to failures during testing. Currently, only one type of mechanical seal has a dedicated rack in the line, while the other types are simply placed on top of the rework bench, along with other components used at this station.

To resolve this, a new rack has been designed to accommodate three additional lanes: two for the high-demand seals and one for the specialties. This new rack system ensures that the seals remain protected and organized, and it mirrors the approach used in the first two workstations for managing specialty parts. From now on, dedicated lanes for specialties will be implemented across all workstations, with the same logic of part sequencing and usage as explained earlier.

All the actions put together lead to improvements in terms of flow, ergonomics, and reduction of NVA/Incidental activities (Figure 6.8, Table 6.2).



Δ VA	0	Δ VA	0	Δ VA	0
Δ INC	0	Δ INC	-1	Δ INC	-3
Δ NVA	-2,8	Δ NVA	0	Δ NVA	0

Figure 6.9: VA, Incidental and NVA comparison AS IS vs TO BE Workstation 2

Phase Description	Action
Seal housing assembly, O-Ring insertion, and air blowing	**Line length reduced**
Insertion of fixed mechanical seal	**Improved material presentation**
Insertion of rotatory mechanical seal and shoulder washer	**Improved material presentation**

Table 6.7: Improvements per sub-phase workstation 2

6.2.5 Workstation 3: Hydraulic Pack

The changes made to this workstation will have the most significant impact on the length of the assembly line. Currently, this section is 3 meters long and contains all the various hydraulic components that could be used in the assembly of an eHM pump.

This setup leads to issues with incorrect material picking, which is not detected by the camera system and can only be identified during the hydraulic test.

In the new layout, the hydraulic components will be placed along the shorter side of the U-shape (Figure 6.9). The decision was made to categorize the hydraulic materials by material type and size family, assigning this information to the first digit of the technical sequence. This will allow the production planning process to group the pumps accordingly.

The new structure will be 7 meters long, but only 1.5 meters will be visible to the operator. The operator will control a kart that moves along trails, displaying only the materials required for the specific family of pumps being assembled.

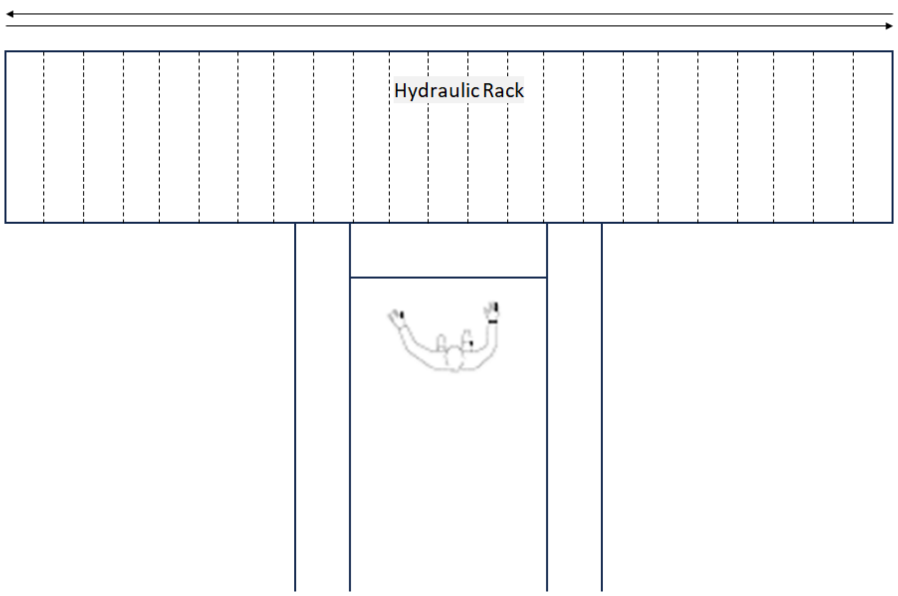
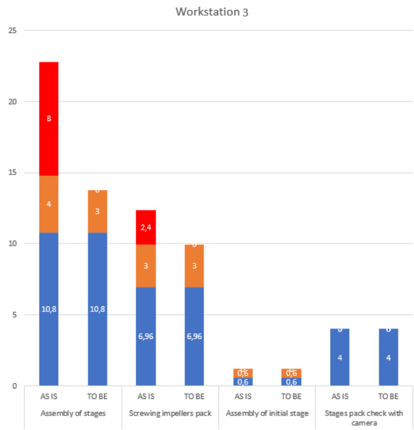


Figure 6.10: Workstation 3 new layout

All the actions put together lead to improvements in terms of flow, ergonomics, and reduction of NVA/Incidental activities (Figure 6.10, Table 6.3).



Δ VA	0	Δ VA	0	Δ VA	0	Δ VA	0
Δ INC	-1	Δ INC	0	Δ INC	0	Δ INC	0
Δ NVA	-8	Δ NVA	-2,4	Δ NVA	0	Δ NVA	0

Figure 6.11: VA, Incidental and NVA comparison AS IS vs TO BE Workstation 3

Phase Description	Action
Assembly of stages	**Line length reduced**
Screwing stages pack	**Line length reduced**
Assembly of initial stage	
Stages pack check with camera	

Table 6.3: Improvements per sub-phase workstation 3

6.2.6 Workstation 4: Pump Body

This workstation served as a benchmark for assessing an alternative kitting methodology, similar to the one already used for the sleeves in the Scuba assembly line, albeit with considerably lower daily volumes (40 pumps per day).

The current AS IS methodology leaves room for the welding operator to autonomously optimize the welding machine setups. However, she does not have precise knowledge of what will be consumed by the assembly line. Instead, she only knows the boxes she needs to fill as they come back empty through the rack.

The rack used by the welding operator is designed with labelled lanes to organize the boxes as she fills them. This results in a structure that, when fully stocked, provides a 5-day coverage for the assembly line. The rack is a large 4-meter wide, 2-meter tall, and 3-meter deep structure (Figure 6.11), occupying a significant amount of space.

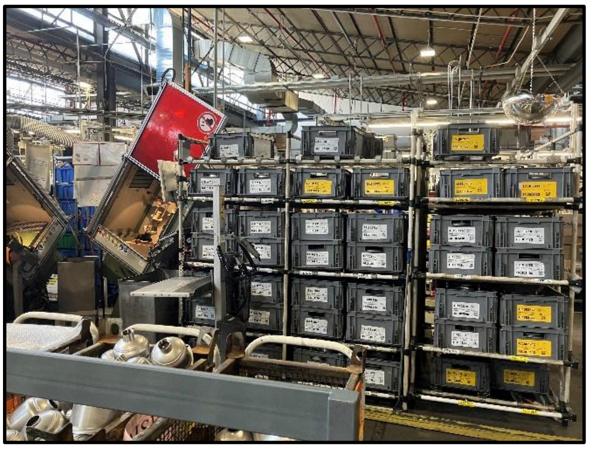


Figure 6.12: AS IS pump body welder rack

The new methodology involves two karts, each carrying 30 pieces, which will be wheeled and moved from the welding station to the assembly line (Figure 6.11). These karts will have two levels, with shaped pallets rolling on them.

The pallets will be numbered from 1 to 3 and sequenced across the two levels. Inside the line, there will be a fixed version of the kart, mirroring the two moving karts. The operator inside the line will take the bodies as the semi-assembled pumps arrive. Once the fixed kart reaches its capacity of 30 pieces, the operator will press a button. This action will release the pallets from the moving kart attached behind the fixed one, while simultaneously sending a signal to the welding station to notify the welding operator that a new moving kart is needed, with a 45-minute window to prepare and bring it to the line.

The welding operator will have the Bill of Materials (BOMs) for the next 2 hours of production, enabling her to kit the moving karts properly. This system works because the line will assemble 42 pumps per hour (320 pumps/7.5 hours), while the welder's output is 50 pump bodies per hour. This allows time for longer setups, mistakes, and other adjustments.

The number of karts may increase by one if, after testing the new methodology, it is determined that the rhythm is unsustainable for the welding operator.

From a material presentation point of view, the operator will no longer have 16 lanes of pump bodies in front of her. Instead, she will only have 8 sequenced pump bodies at a time. This change will reduce the space occupied inside the line, eliminate the double handling of pump bodies, cut inventory (coverage reduced from 5 days to a maximum of 2 hours), and minimize the risk of picking errors.

In the AS IS configuration, after the pump body was screwed into the motor adapter, a visual check of the four screws was necessary, including marking each screw with a marker. This manual check is inefficient and time-consuming. The new process will integrate a software-based verification via a supervisor system connected to a poka-yoke on the working bench. The pump will only proceed with the process if the check confirms the screws are properly secured, eliminating unnecessary steps and improving process reliability.

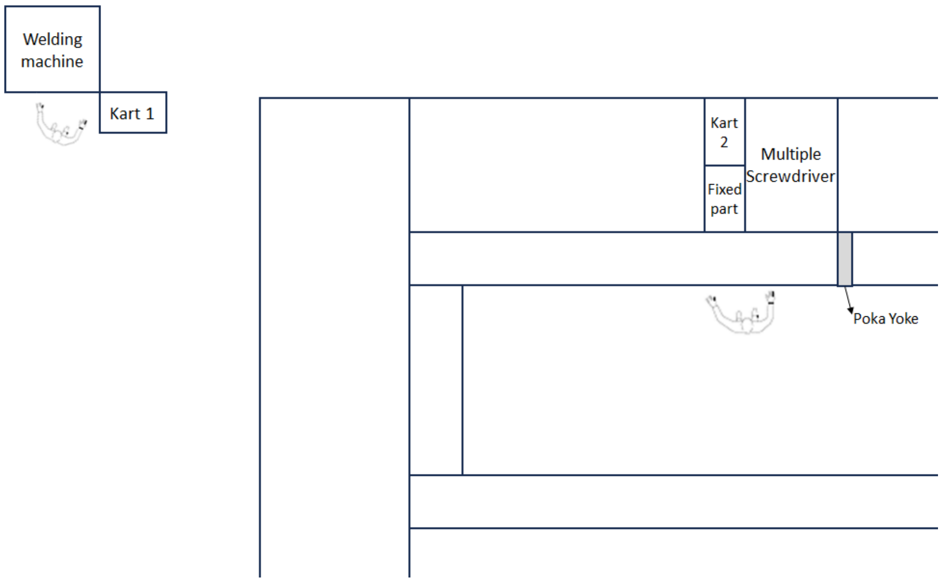
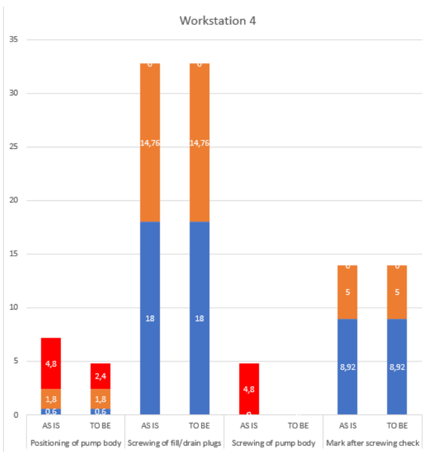


Figure 6.13: Workstation 4 new layout

All the actions put together lead to improvements in terms of flow, ergonomics, and reduction of NVA/Incidental activities (Figure 6.13, Table 6.4).



Δ VA	0	Δ VA	0	Δ VA	0	Δ VA	0
Δ INC	0	Δ INC	0	Δ INC	0	Δ INC	0
Δ NVA	-2,4	Δ NVA	0	Δ NVA	-4,8	Δ NVA	0

Figure 6.14: VA, Incidental and NVA comparison AS IS vs TO BE Workstation 4

Phase Description	Action
Positioning of pump body	**Line length reduced**
Screwing of pump body	
Mark after screwing check	**Poka Yoke implemented**
Screwing of fill/drain plugs	

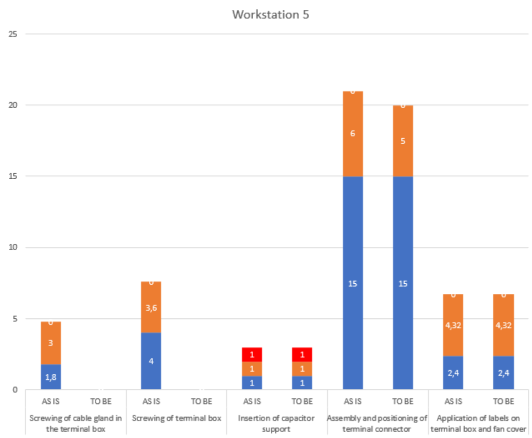
Table 6.4: Improvements per sub-phase workstation 4

6.2.7 Workstation 5: Electrical Parts

This station has undergone changes in both material presentation and process steps:

- Material presentation: Previously, materials were presented with nearly all their variations available, which increased the likelihood of picking mistakes. This issue has been addressed by dedicating lanes only to high-volume components, referred to as "high runners."
- Process steps: The process of screwing the terminal box and assembling the cable gland has been moved to Workstation 1, streamlining the workflow and reducing the complexity of this station.

All the actions put together lead to improvements in terms of flow, ergonomics, and reduction of NVA/Incidental activities (Figure 6.14, Table 6.5).



Δ VA	-1,8	Δ VA	-4	Δ VA	0	Δ VA	0	Δ VA	0
Δ INC	-3	Δ INC	-3,6	Δ INC	0	Δ INC	-1	Δ INC	0
Δ NVA	0	Δ NVA	0	Δ NVA	0	Δ NVA	0	Δ NVA	0

Figure 6.15: VA, Incidental and NVA comparison AS IS vs TO BE Workstation 5

Phase Description	Action
Screwing of cable gland in the terminal box	**Moved to workstation 1**
Screwing of terminal box	**Moved to workstation 1**
Insertion of capacitor support	
Assembly and positioning of terminal connector	**Improved material presentation**
Application of labels on terminal box and fan cover	

Table 6.5: Improvements per sub-phase workstation 5

6.2.8 Workstation 6: Electrical and Hydraulic test

These two workstations have not undergone material presentation changes; however, significant improvements have been made in terms of testing logic and hardware.

- Electrical Test

The electrical test is critical, as it is performed on 100% of the pumps produced. A major enhancement has been introduced with the implementation of a new test machine, which addresses the variability caused by specialized and custom pumps.

The old machine required different setups for different pump versions and sometimes required manual connections between the terminal and an external connector. The new machine eliminates this by introducing a sliding door mechanism. If the test is not performing correctly, the sliding door will rise, allowing the operator to correctly position the pump under the machine. Once positioned, the operator can simply run the test, and the door will close automatically, with no further setup required.

This update significantly reduces incidental activities, making the process smoother and more efficient (Figure 6.15, Table 6.6).

- Hydraulic Test

The hydraulic test, which is currently the largest bottleneck in the line, has been moved closer to the assembly process, eliminating its previous isolation. This change required a re-evaluation of the test frequency due to the test's current machine time of 94 seconds, which exceeds the takt time and causes line imbalances.

Under the existing setup, multiple tests may be required in one day, causing significant disruptions. To address this, the new logic for hydraulic testing is as follows:

15. A test will be performed every time the impeller changes.
16. Every 30 pumps with the same impeller will be tested, unless the impeller has already been changed.

This new testing logic significantly reduces the frequency of consecutive tests, with only 2-4 consecutive tests expected per day on average. Although this could initially cause line imbalances, it is expected that the line will eventually self-balance.

Given the complexity of simulating these changes, the implementation will include a buffer of three pumps before the electrical test to accommodate these adjustments.

If this solution does not resolve the issues, the hydraulic test may be re-isolated while further improvements are explored, either in testing methods or in faster machines for conducting the test.

Δ VA	0	Δ VA	0	Δ VA	0	Δ VA	0	Δ VA	0
Δ INC	-5,2	Δ INC	0	Δ INC	0	Δ INC	0	Δ INC	0
Δ NVA	0	Δ NVA	0	Δ NVA	0	Δ NVA	0	Δ NVA	0

Figure 6.16: VA, Incidental and NVA comparison AS IS vs TO BE Workstation 6

Phase Description	Action
Static and electric testing	**New Xytest better performing**
Setup for hydraulic test	
Test conclusion and draining of pump	
Screwing of terminal box cover	
Insertion of thread protection caps	

Table 6.6: Improvements per sub-phase workstation 6

6.2.9 Workstation 7: Closure + Packaging

This workstation underwent changes in material presentation to improve efficiency and organization:

Previously, the packaging components were presented in a way that required the operator to access the back of the station. If the packaging type changed, the operator would need to move all components being used and replace them with the new ones. Additionally, the large number of manuals used for assembly were stored in a dedicated rack located in the middle of the line, which was not ideal for smooth operations.

Two key improvements were implemented:

- Manuals organization: The manuals are now paired based on their usage frequency, with the three high-frequency manuals grouped together. This ensures that the most frequently used manuals are easily accessible and reduces the need for unnecessary movement.

- Packaging station redesign: The packaging station was redesigned by adopting a layout similar to the one used in the BG assembly line (Figure 6.16). The new configuration includes:

Two horizontal levels for organizing packaging components: one level dedicated to high-frequency packaging components and the other for specialty items.
On top of these two levels, six vertical lanes were added to store packaging components. Three of these lanes are dedicated to high-frequency items, while the remaining three are for specialty components.

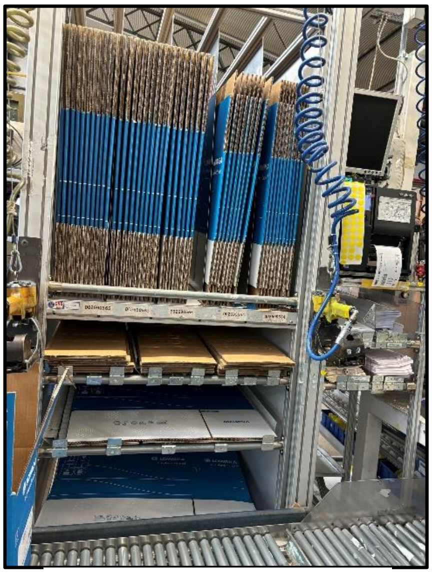
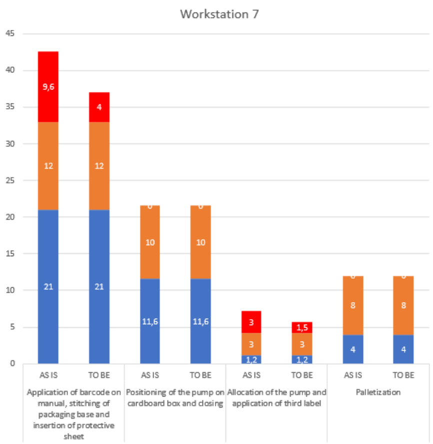


Figure 6.17: BG packaging rack

All the actions put together lead to improvements in terms of flow, ergonomics, and reduction of NVA/Incidental activities (Figure 6.17, Table 6.7).



Δ VA	0	Δ VA	0	Δ VA	0	Δ VA	0
Δ INC	0	Δ INC	0	Δ INC	0	Δ INC	0
Δ NVA	-5,6	Δ NVA	0	Δ NVA	-1,5	Δ NVA	0

Figure 6.18: VA, Incidental and NVA comparison AS IS vs TO BE Workstation 7

Phase Description	Action
Application of barcode on manual, stitching of packaging base and insertion of protective sheet	**Improved material presentation**
Positioning of the pump on cardboard box and closing	
Allocation of the pump and application of third label	**Line length reduced**
Palletization	

Table 6.7: Improvements per sub-phase workstation 7

6.3 Final Relayout

The one presented in Figure 6.18 is the definitive final relayout.

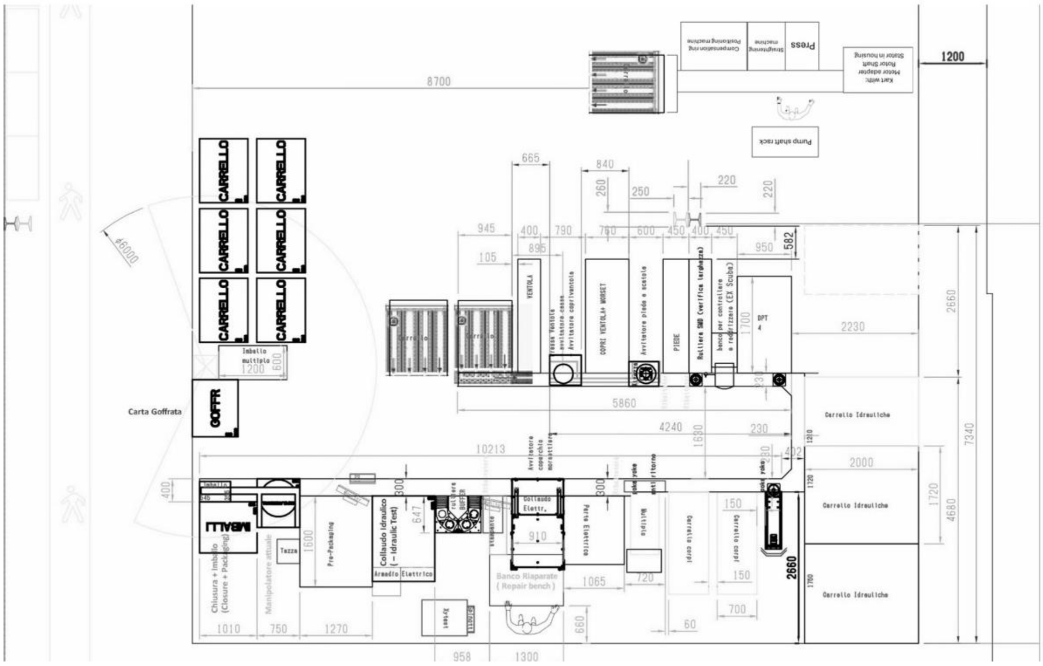


Figure 6.19: Final Relayout

This layout shows how much the space is not optimally utilized in the AS IS configuration, leading to 35% saving in terms of space, going from 126 square meters to 82,4 square meters (Figure 6.19).

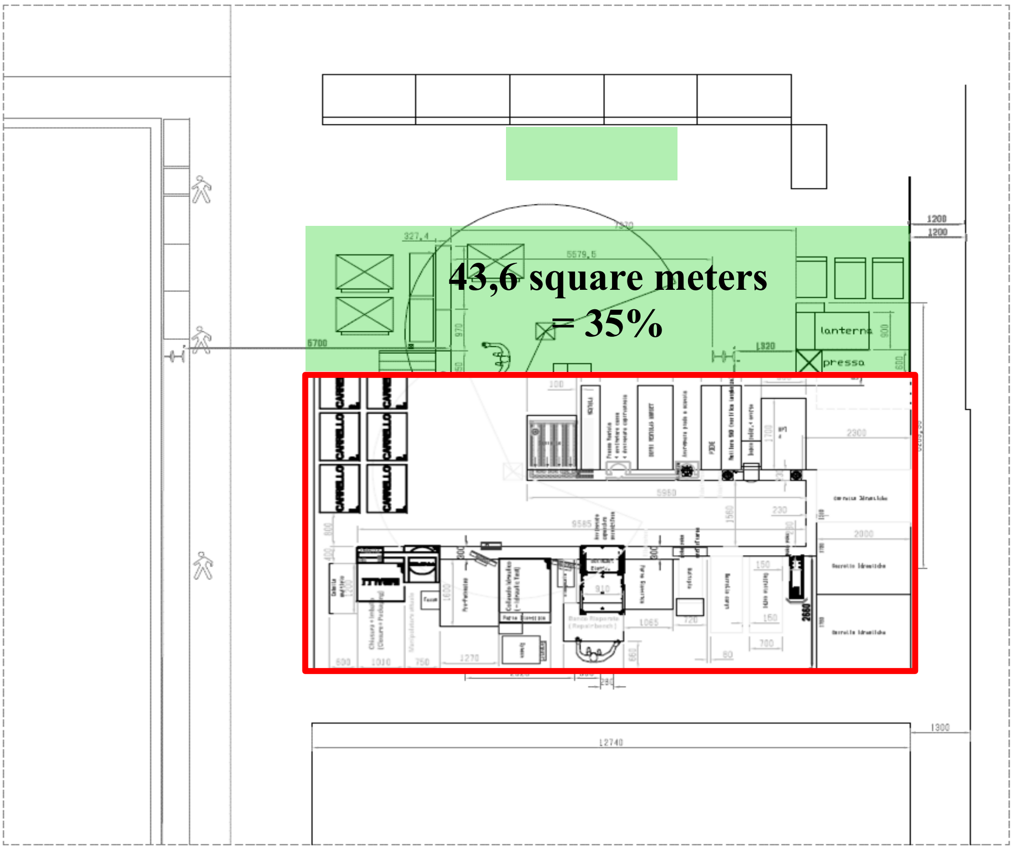


Figure 6.20: Space Saving with new relayout

6.3.1 Operator Balance Chart

The assembly line in the AS IS configuration is both wasting lot of space and working in a not balanced situation.

In the TO BE configuration, the line will work in one shift (7,5 hours available time), yielding to produce 320 pumps per day, and the new Total Cycle Time will be 347 seconds (- 24%).

The takt time with the TO BE configuration is then calculated as:

$$takt\ time_{TO\ BE\ (1\ shift)} = \frac{450\ min/d}{320\ pcs/d} = 1{,}41\ min/pc = 85\ s/pc$$

And the line can work at this rhythm by employing 4 operators per day plus the operator working outside the line (Figure 6.20):

$$n°\ of\ operators_{AS\ IS\ (2\ shifts)} = \frac{347\ s/p}{85\ s/p} = 4.1\ operators = 4\ operators$$

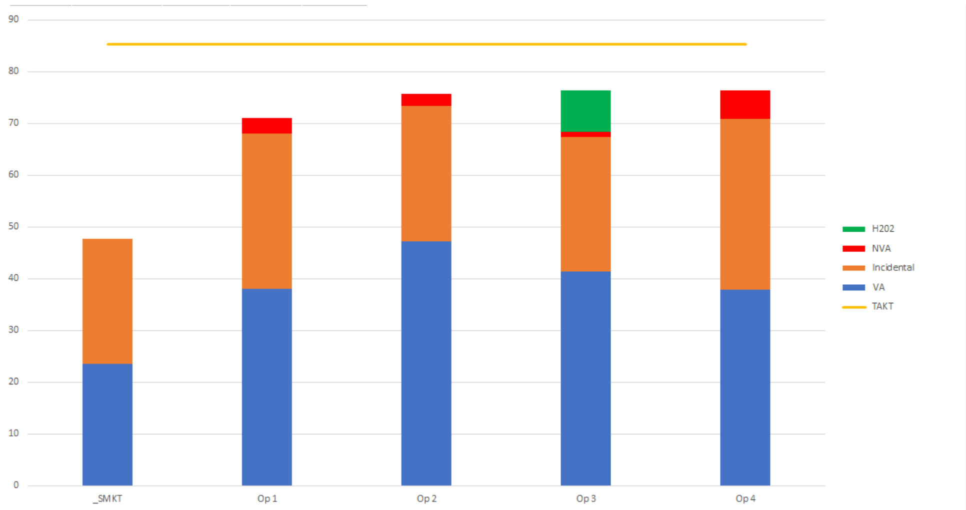


Figure 6.21: Operators Balance Chart of the TO BE configuration

The balancing of the TO BE configuration does not strictly follow the rules of the canonical operators balance chart, that is because the first operator will be bound to the kitting isle and her parts of the process cannot be distributed among the other operators.

The operator working outside will be working also for the HM with sleeves assembly line in the future, and that will saturate its time levelling the chart.

6.3.2 Spaghetti Chart

The new layout brings significant improvements in terms of efficiency and productivity, with the most notable change being a more linear flow inside the line, eliminating mixed routes.

An option was considered where a single operator would handle the same pump throughout the entire process, creating a circular flow with non-repetitive routes. However, this idea was discarded due to practical limitations: not all operators have the same speed when performing each step. Some are faster at certain operations and slower at others, depending on individual characteristics.

Given this, it was decided to maintain the existing approach, with operators working on the same tasks and moving back and forth to retrieve the semi-assembled pump that the previous operator has worked on. To avoid excessive repetition, the hourly rotation system was kept, allowing operators to switch positions every hour.

The flow inside the new line is showed with the spaghetti chart in Figure 6.21.

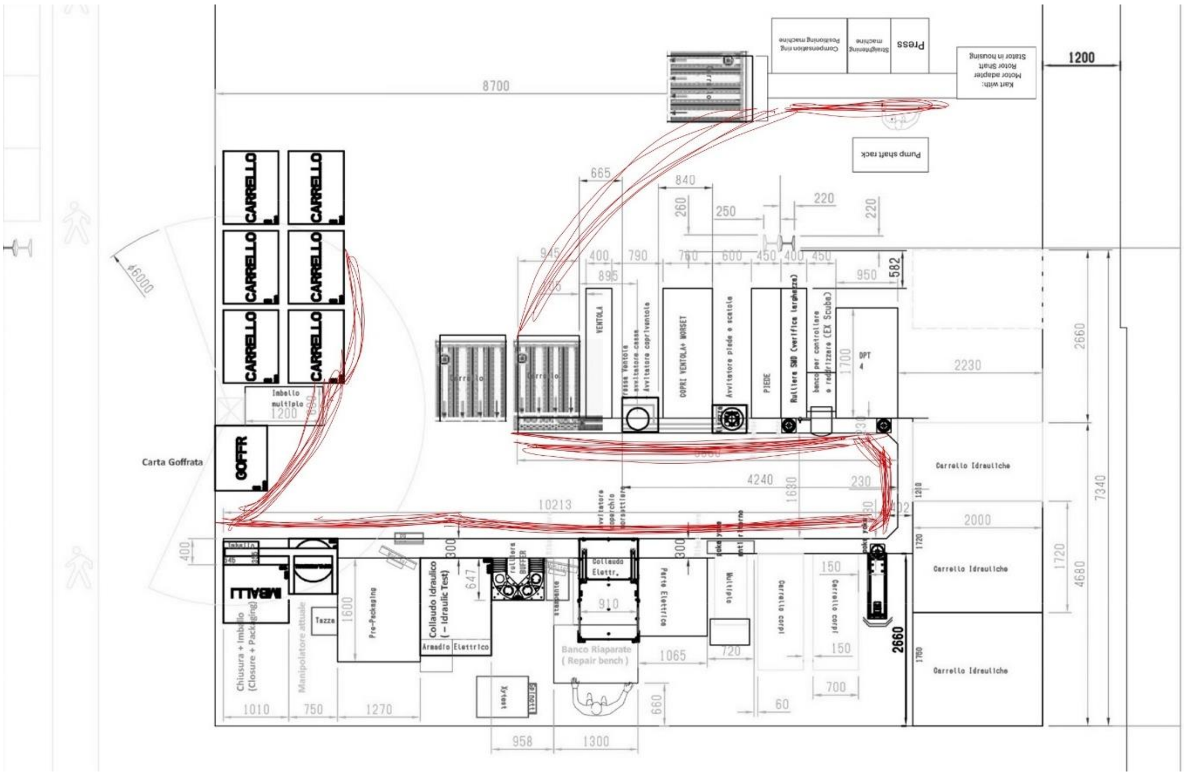


Figure 6.22: Spaghetti Chart in the new layout

6.3.4 Savings

The analysis done on this assembly line, and all the actions the were made inside the line brought concrete improvements in terms of continuous flow, ergonomics, cleanliness and of course also money.

In terms of units per person per hour, the line went from 7,9 pcs/person/hour to 10,4 pcs/person/hour, with 31% increment.

$$Efficiency\ AS\ IS = \frac{\frac{320\ pieces}{2{,}9\ operators}}{14\ hours} = 7{,}9\ \frac{\frac{pieces}{person}}{hour}$$

$$Efficiency\ TO\ BE = \frac{\frac{320\ pieces}{4{,}1\ operators}}{7{,}5\ hours} = 10{,}4\ \frac{\frac{pieces}{person}}{hour}$$

This can be transformed into monetary savings by considering that the delta between the Total Cycle Time AS IS and the Total Cycle Time TO BE is 107 seconds.

By converting this in delta hours per day, we can then calculate how many FTE[9] are eliminated:

[9] Full Time Equivalent

$$Hours\ Saved\ Daily = \frac{107\ seconds\ x\ 320\ pumps}{3600} = 9{,}5\,\frac{hours}{day}$$

$$delta\ FTE = \frac{9{,}5\,\frac{hours}{day}}{7{,}5\ hours} = 1{,}27\ FTE$$

After having calculated the FTE saved, by multiplying the result with the yearly tariff for 1 FTE (50.000 Eur), the yearly saving will be 63.407 Eur/year.

$$Saving\ per\ year = 1.27\ FTE\ x\ 50.000\,\frac{Eur}{year} = 63.407\,\frac{Eur}{year}$$

6.4 Conclusions

The TO-BE configuration describes a reshaped main assembly line in keeping with lean principles.

This chapter expounds how targeted actions (kaizen bursts) and standardized workstations solve inefficiencies from AS IS state.

Expected outcomes are clearly articulated to include more streamlined workflows, reduced lead times, better operator balance, and waste minimization.

Such relayout is to create a model cell that could be scaled out to other production lines, embedding lean thinking deep into the organization.

Chapter 7
Conclusions

The transformation journey undertaken at Lowara SRL shows how the practice of lean manufacturing makes a difference in achieving sustainable operational improvement and waste reduction.
Based on this thesis, a detailed relayout of an assembly line was done, and that showed the effect of lean methodologies on the production process, establishing the base for further transformations to be undertaken within the organization.

It started with the thorough study of the AS-IS configuration and unravelled certain key bottlenecks regarding space utilization, inventory management, and process flow. Application of different lean tools helped in developing the target TO-BE state. The proposed model cell layout was designed in such a way that it enhanced the workflow and production capacity for a single shift production to meet the production demand. Ultimately, the model cell provided the benchmark for quantifying lean's potential gains over conventional methods so that the principles could be applied with more confidence to other areas of production.

One of the successes of his study included the space relayout; having managed to reduce occupied space by 35%, thus smoothing the flow of operations as a whole. Indeed, productivity went up, evidenced in a 31% unit increase per person per hour, proving that lean principles do yield a few advantages in operational output.
This resulted in an estimated annual saving of €63,407 achieved by reducing cycle times and labor hours. Such a result further confirm the fact that lean transformations do indeed yield significant economic and operational benefits if properly implemented in manufacturing setups.

However, not all was so smooth as far as implementation was concerned.
First and foremost, there was a need for cultural change since principles of lean basically called for a shift from the conventional mode of production to a continuous improvement culture. Training and communication were important in overcoming initial employee resistance to change and in aligning them with the lean values.
A balanced workflow had to be designed, taking care of the difference in operator speed and skill, to ensure that efficiency compromises did not happen in team members. Another key insight was the flexibility required in the application of lean methods. Though lean advocates

homogeneity in the workflow process, there were some adaptations necessary in this respect to ensure specific needs are met within the processes. This at least told us that in some instances, a flexible approach may be what is required to obtain optimal results.

Using these findings, the following recommendations can be made to scale lean principles across Lowara's operations.
Meanwhile, documentation of layouts, process adjustments, and lean methods implemented in this model cell will create a sound basis for best practices that can easily be spread throughout the organization. Continuous training will also run side by side to foster a proactive attitude in employees to highlight inefficiencies and ways to get rid of them. Increasing the number of value stream maps to other production lines will further ensure that these areas align with the lean philosophy, optimizing material and information flows throughout the plant.

In brief, this thesis confirms that with a strategic vision, lean transformation can bring significant efficiency gains, cost reduction, and better space utilisation. The best practices from the model cell implementation represent a strategic path to improving Lowara S.R.L.'s production processes. This is a transformation that shall be successful, in the end, not only with the technical application of lean tools but also in the creation of a continuous improvement and innovation culture.

References

Becker C. & Scholl A., 2006, A survey on problems and methods in generalized assembly line balancing. *European journal of operational research*, vol. 168, n. 3, pp. 694-715.

Cooper, R. G. (1988). The new product process: A decision guide for management. *Journal of Marketing Management*, vol. 3, n. 3, pp. 238–255.

Doran G. T., 1981, *There's a S.M.A.R.T. Way to Write Management's Goals and Objectives, Management Review*, n. 70, pp. 35-36.

Isniah, S., Purba, H. H., & Debora, F., 2020. Plan do check action (PDCA) method: literature review and research issues. *Jurnal Sistem dan Manajemen Industri*, *4*(1), 72-81.

Jackson T. L., 2006, *Hoshin Kanri for the lean enterprise: developing competitive capabilities and managing profit*, CRC Press.

Johnson K. G. & Khan M. K., 2003, A study into the use of the process failure mode and effects analysis (PFMEA) in the automotive industry in the UK. *Journal of Materials Processing Technology,* vol. 139, n. 1-3, pp. 348-356.

Krafcik J. F., 1988, Triumph of the lean production system, *MIT Sloan Management Review*, vol. 30, n. 1, pp. 41-52.

Liker J.K., 2003, *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill.

Michalska, J., Danuta S., 2007, The 5S methodology as a tool for improving the organization. *Journal of achievements in materials and manufacturing engineering*.

Muchiri, P., & Pintelon, L., 2008, Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion. *International journal of production research*, *46*(13), 3517-3535.

Ohno T., 1988, *Toyota production system: beyond large-scale production*, Crc Press., New York.

Pampanelli A. B., Found P., Bernardes A. M., 2014, *A Lean & Green Model for a production cell*, Journal of cleaner production, n. 85, pp. 19-30.

Rother M. & Harris R., 2001, *Creating Continuous Flow: An Action Guide for Managers, Engineers & Production Associates. A lean tool kit method & workbook*, Lean Enterprise Institute, Cambridge, MA.

Rother M. & Shook J., 1999, *Learning to see*, Lean Enterprise Institute, Brookline

Shook, J., 2007, *Lean production simplified*. Productivity Press.

Slack, N., Brandon-Jones, A., & Burgess, N., 2022, *Operations Management (10th edition)*. (10 ed.) Pearson.

Toussaint J. & Adams E., 2015, *Management on the mend: The healthcare executive guide to system transformation*, ThedaCare Center for Healthcare Value.

Womack, J. P., Jones, D. T., & Roos, D., 1990, *The machine that changed the world: The story of lean production*. Harper Business.

Womack, J. P. & Jones, D. T., 2003, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation, Revised and Updated*, Harper Business.

Zhao Y., Kramer T., Brown R., & Xu X., 2011, *Information modelling for interoperable dimensional metrology*, Springer Science & Business Media, p. 301.

List of Websites

Constable, H., 2024, *Continuous Flow is Key to Lean Manufacturing - Lean Manufacturing Junction*. Lean Manufacturing Junction. Available at https://lean-manufacturing-junction.com/2024/10/continuous-flow-is-key-to-lean-manufacturing/

Harris Lean Systems, n.d., *About HLS – Harris Lean Systems, Inc.* (n.d.). Available at https://harrisleansystems.com/?page_id=45

Hessing, T., 2022, *Spaghetti Diagram*. Six Sigma Study Guide. Available at https://sixsigmastudyguide.com/spaghetti-diagram/

Lean Enterprise Institute, 2020, *Operator Balance Chart*. Lean Enterprise Institute. Available at https://www.lean.org/lexicon-terms/operator-balance-chart/

Learn Lean Sigma, 2024, *Guide: Non-Value Add Analysis*. Learn Lean Sigma. Available at https://www.learnleansigma.com/guides/non-value-add-analysis/

Meardon, B. E. (n.d.). *Gantt Charts explained [+ how to create one] | Atlassian*. Atlassian. Available at https://www.atlassian.com/agile/project-management/gantt-chart

Pereira, H., 2024, *Gemba and its meaning – the heart of lean management*. Kaizen Institute Consulting Group. Available at https://kaizen.com/insights/gemba-meaning-lean-management/

Skhmot, N., 2017, The 8 Wastes of Lean. The Lean Way Blog. Available at https://theleanway.net/The-8-Wastes-of-Lean

Tsonev, N., n.d., *The lean transformation model in knowledge work*. (n.d.). Kanban Software for Agile Project Management. Available at https://businessmap.io/lean-transformation/model

Xylem US, n.d., *Vision & Values | Xylem US*., Xylem Water Solutions & Water Technology. Available at https://www.xylem.com/en-us/careers/vision-values/

Xylem US, n.d., *Water & Wastewater Products & Services | Xylem US*., Xylem Water Solutions & Water Technology. Available at https://www.xylem.com/en-us/products--services/