Politecnico di Torino

MSc in Automotive Engineering

Strategic Warehouse Redesign and Internal Logistic Flow Optimization: The Tenneco, Inc. Case Study

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Contents

List of Figures

Abstract

This thesis explores the study and optimization of material supply flows to production lines and the improvement of warehouse logistics through a detailed analysis and redesign of the layout, aiming for a more efficient organization and storage of goods. The primary objective is to enhance logistics efficiency through the implementation of an inter-company Milk-Run system, aimed at reducing operational costs by addressing key factors such as labor requirements, transportation distances and times, flow frequencies, and the types and number of handling and transportation equipment utilized. Let's take a closer look at the Runner Project, a fascinating initiative reviewed at Tenneco Group's facility in Chivasso. As a major player in the automotive OEM and aftermarket sectors, Tenneco is constantly looking for ways to grow. The Runner Project aligns with this vision by focusing on improving productivity both locally and globally. It began with an emphasis on optimizing how the plant operates, particularly when it comes to warehouse efficiency. But that's not all—it later expanded its scope to include a detailed analysis aimed at fine-tuning internal logistics, which covers everything from supplying the production line to managing waste disposal effectively. Given the growing need for modern enterprises to minimize waste and eliminate inefficiencies, this study conducted an in-depth assessment of the company's challenges. A structured reorganization of warehouse operations was carried out using Lean Manufacturing methodologies to achieve both economic and organizational advantages. By integrating these improvements with repetitive and standardized procedures, a sustainable continuous improvement system (*Kaizen*) was established, leading to significant cost reductions in material handling and storage. The findings and results obtained from this research at the Chivasso facility (TO) provide a foundation for further internal process enhancements and offer a scalable model that Tenneco can implement across its global operations.

Introduction

The aim of this thesis is to improve and optimize internal logistics flows related to the sup-ply of production lines through the implementation of the inter-company Milk-run concept. The "Runner," responsible for replenishing production across the entire facility, performs several tasks during a shift. These include retrieving raw materials from the dedicated internal warehouse (managed under a FIFO system), transporting them to the production lines for use by operators at designated workstations, moving semi-finished products between lines, transporting finished goods to the designated shipping area, and disposing of waste bins. Previously, these activities were not governed by a clear and precise schedule, but they were managed on an ad hoc basis depending on immediate needs. This lack of standardization led to significant confusion in the forklift operator's workflow, resulting in inefficient operations with no structured activities during their shift. Consequently, the processes exhibited substantial inefficiencies, presenting an opportunity for significant improvements aimed at waste reduction, both in terms of time and, subsequently, costs. Additional criticalities in warehouse management were identified, particularly in the ability to quickly supply each workstation and locate materials efficiently. Planning a warehouse, carefully determining its location and size, can significantly mitigate and reduce waste of energy, materials, and time. In practice, reducing waste also allows improvements in the quality of the finished product and streamlines the production process. A more constrained management of space translates into better overall efficiency. For this reason, it was crucial to address the issues of warehouse size and layout reorganization within a manufacturing environment. In such settings, warehouses serve as dedicated spaces for storing various quantities and types of materials near the production lines that require them. The warehouse is an essential element in managing the dynamics of modern production systems, as it facilitates cost savings by counteracting overproduction and waste, which are common issues in daily operations. Warehousing is a key component of the "Lean Manufacturing" philosophy, which provides a framework for optimizing production processes and fostering continuous improvement within companies. To fully realize the potential of shelving systems, it is vital to understand the corporate context in which they are implemented. This strategic environment is the layout. Lean tools, which will be explored in this thesis, find their full application in the internal reorganization of layouts. In particular, an optimized arrangement of spaces and internal pathways that accommodate forklift movement ensures effective supply to production lines. Proper placement of supermarket shelving within the layout simplifies operations for internal staff, highlights inefficiencies early, and ultimately reduces waste, such as excessive in-line stock.

The case study company, Tenneco, encountered significant issues related to poor warehouse management, which negatively impacted production. At times, forklift operators were unable to deliver raw materials to production lines on time, primarily due to slow and challenging searches for pallets within the warehouse. The topic of warehouse management including its implementation steps, sizing, and positioning within the company is of great importance. Determining its location and capacity requires assessing the actual usage of each component in producing different products, followed by allocating appropriate space within the shelving systems.
Managing spaces and components within a manufacturing context involves specific

considerations. Firstly, the current market demand for product diversification prevents achieving significant economies of scale in production volumes. This leads to a proliferation of various component types, which must be managed in terms of space, footprint, and timely reordering from suppliers. Furthermore, globalization complicates the logistics of transportation and delivery schedules due to the geographical distribution of customers and suppliers worldwide. Poor internal organization of production lines and their respective storage areas would exacerbate these challenges, making them much harder to manage. This is why the Lean philosophy and its associated tools are highly relevant in the context of Tenneco. These aspects will be explored in the subsequent chapters.

In *Chapter 1*, will be defined and discussed the fundamental concepts of logistics and its integration into the overall operational cycle of a company. This chapter will reference well-known theoretical topics such as the 5S methodology, the 7 types of waste, continuous improvement (*Kaizen*), the Kanban system, visual management approach, activities standardization, the FIFO system, the concept of inter-company Milk-run, and material handling. Additionally, the chapter will address the topic of Total Flow Management and how its principles and methods can influence the supply chain to achieve improved internal logistics flow.

In *Chapter 2*, will be presented the company and the industrial context in which it operates, along with the materials produced and the related production and informational processes. The type of work carried out during the project will be described, beginning with an outline of the structure and objectives of the various phases and studies undertaken, followed by a critical analysis of the findings.

Chapter 3 and *Chapter 4* will focus on analyzing the two main warehouses dedicated to raw materials and packaging, contextualized from a Lean perspective. In these chapters, we'll explore the results we've achieved from improving how we manage our stored goods and reorganizing our layout. We'll focus on the benefits we've experienced along the way. We'll take a closer look at some key principles of the Lean philosophy, revisiting the main ideas from the Toyota Production System (TPS) and examining various corporate cases where they've been successfully applied.

Chapter 5 will dive into the logistics of the project, laying out the steps we took in analyzing, designing, and testing our internal Milk-run system, specifically personalized to our company's unique needs. The logistical process will be described, encompassing the retrieval of materials from the warehouse, their use in production, the supply of production lines necessary to execute the production plan, and the shipment of the finished product.
Additionally, the chapter will include the "To Be" analyses and corrective actions implemented to manage and optimize the flow through appropriate documentation, procedures, and signage in line with Visual Management principles. A Cost-Benefit Analysis will also be discussed, summarizing key outcomes such as streamlined production activities characterized by improved efficiency and speed and a reduction in related logistics costs alongside a significative decrease in production line supply times.

1 Lean Manufacturing Principles: Tools for Logistic Optimization

The objective of this chapter is to address and describe the challenges associated with internal logistics flows, production line supply, and the reorganization of the warehouse's internal layout, using the principles of Lean Production as a foundation. The aim is to provide a theoretical overview of the topic to contextualize the analysis conducted in this thesis.

1.1 Introduction

Lean Production is all about making industrial processes work better. It's focused on cutting down waste while still delivering great value to customers. This approach came about from the need to be more efficient and to keep up with changing market needs, and now it's a key part of modern manufacturing. As time has gone on, different scholars have interpreted the Lean concept in various ways, depending on what they were trying to achieve. The fundamental principle, however, re-mains the reduction of waste while continuously making incremental improvements. This is often referred to as Lean-Kaizen, a tool for simultaneously achieving excellence in quality, cost, and delivery. It emphasizes the active participation of every individual in their activities, aligning the company's objectives toward continuous improvement [1].

In his research, Kumar uses Lean principles to create a Value Stream Mapping (VSM) approach. This method compares the current state of processes to a future ideal state, focusing on the value created at each step along the way. It turned out to be quite effective in the case he studied, leading to better use of both human and physical resources, shorter production lead times, and more consistent output. However, it also pointed out that successfully applying these techniques really calls for a deep understanding of the entire system to fully reap the benefits.

The core idea behind Lean Manufacturing is to minimize activities that don't add value, all while enhancing quality and performance [2]. Logistics is linked to the broader concept of supply chain management, a system comprising interconnected people, activities, information, and resources designed to create and deliver a product to the customer. Within any process, three types of activities can be identified. According to Womack and Jones [3], the percentage weight of these activities is distributed as follows:

- 5% are activities that add real value to the product
- 35% are necessary but non-value-adding activities
- 60% are unnecessary activities

This underscores the need for Lean tools to reduce the impact of necessary but non-value-adding activities while simultaneously identifying and eliminating unnecessary ones. The propagation of Lean thinking also reveals varying impacts depending on the context in which it is applied. For instance, in small and medium-sized enterprises, is challenging achieving positive results in a short time. These environments are often characterized by low productivity and flexibility, poor production performance, and high inventory levels. This is partly due to a preference for short-term strategic orientations, a lack of initiative and new technologies, difficulties accessing funding, and ineffective leadership with inadequate skills. However, studies have shown that implementing Lean techniques (e.g., VSM, pull Kanban, visual management, 5S...) reduces flow time, significantly improving customer service lev-els. The application of Kaizen principles has also demonstrated average reductions in unit costs, better utilization of production floor space, and enhanced communication networks [4].

1.2 Historical Background

The roots of Lean Production trace back to the early 20th century with the emergence of mass production techniques pioneered by Henry Ford. Ford's assembly line revolutionized manufacturing by enabling large-scale production at reduced costs. However, the concept of Lean as it is known today was formalized in the mid-20th century by Toyota in Japan. When faced with tight resources and fierce competition, Toyota came up with the Toyota Production System (TPS), a groundbreaking way to handle manufacturing that really zeroes in on cutting out waste.

1.2.1 Toyota Production System (TPS)

The Toyota Production System, or TPS, is considered one of the most impactful approaches in today's manufacturing world. It was created by Toyota in the mid-1900s, fundamentally changing how industrial processes are overseen. Taiichi Ohno, who is often seen as the mastermind behind TPS, explained its key concepts in his important book, Toyota Production System: Beyond Large-Scale Production. In this chapter, we'll explore the roots, main principles, and essential elements of TPS, emphasizing its lasting importance in reaching operational excellence.

The story of Toyota Production System (TPS) really begins in Japan after World War II, a time when resources were tight and the economy was struggling. Back then, Toyota was just a small car maker trying to keep up with the big players in the American auto industry, known for their mass production techniques. Taiichi Ohno and Eiji Toyoda looked to the innovative assembly line of Henry Ford and even the efficiency of American supermarkets to find inspiration to create something that would work for their own situation.

The implementation of TPS has transformed Toyota into one of the most successful and respected automotive manufacturers in the world. Key benefits include:

- Reduced costs: through waste elimination and efficient use of resources
- Improved quality: by preventing defects and ensuring consistent standards
- Greater flexibility: enabling quick adaptation to changes in market demand

TPS has influenced industries worldwide, forming the basis for Lean Production and inspiring methodologies.

1.2.2 Kaizen: the philosophy of continuous improvement

At the heart of successful Lean activities lies a profound mindset: every decision made with-in the company must be seen as a step forward, involving the entire organizational structure and the actions of each individual. A key concept in this context is improvement, which, in the Toyota Production System (TPS), is the cornerstone of competitiveness against massive assembly line operations like Ford. This concept is encapsulated in the Japanese term "Kai-zen" [5], derived from "*Kai*" (change) and "*Zen*" (better), signifying a process of continuous improvement. Kaizen advocates for incremental, daily progress, which can ex-tend beyond the workplace to every aspect of life.
As illustrated in Figure 1.1, both Kaizen and Kairyo are integral to an organization's improvement process. Kairyo is a Japanese term that refers to a sudden change driven by a radical improvement that transforms the system in a leap, rather than gradually evolving it through small, continuous improvements (Kaizen). This type of change may stem from external factors, such as scientific discoveries, new production processes, or shifts in market dynamics, or internal factors, such as process re-engineering. In all cases, Kairyo requires a decision by top management or someone with significant influence, a substantial or moderate investment, a great effort of will, and does not involve all stakeholders, often disregarding dissenting voices and potential conflicts. A radical improvement program must be paired with change management strategies to facilitate the acceptance of changes, emphasizing positive aspects while minimizing negative ones.

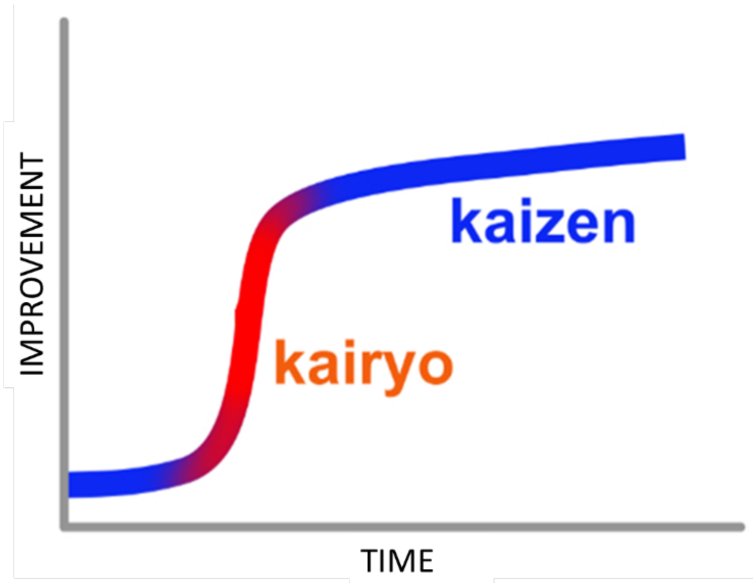

Figure 1.1: Differences between the concepts of Kaizen and Kairyo based on Time and Improvement variables [6]

Central to the Toyota Production System (TPS), Kaizen emphasizes incremental progress, involving every level of an organization in identifying and implementing improvements. Kaizen is guided by several foundational principles that define its approach to continuous improvement:

1. Focus on incremental changes: progress is achieved through small, consistent adjustments rather than radical transformations
2. Engagement of all employees: Kaizen empowers workers at every level, from line operators to executives, to contribute ideas and solutions
3. Elimination of waste (MUDA): efforts are directed toward identifying and removing inefficiencies in processes (there will be a dedicated paragraph about this topic)
4. Data-driven decision making: improvements are based on objective analysis and measurable outcomes
5. Respect for people: collaboration and shared responsibility are central to Kaizen, fostering a culture of mutual trust and respect

The Kaizen process is often structured around the **PDCA** (Plan-Do-Check-Act) cycle, a systematic approach to problem-solving and process improvement:

- **Plan**: identify the problem or opportunity, analyze root causes, and develop a plan for improvement
- **Do**: implement the proposed solution on a small scale
- **Check**: evaluate the results to determine the effectiveness of the solution
- **Act**: standardize the successful changes or revise the plan if needed, before scaling the implementation

This iterative process ensures that improvements are thoroughly tested and refined, minimizing risks and maximizing effectiveness.

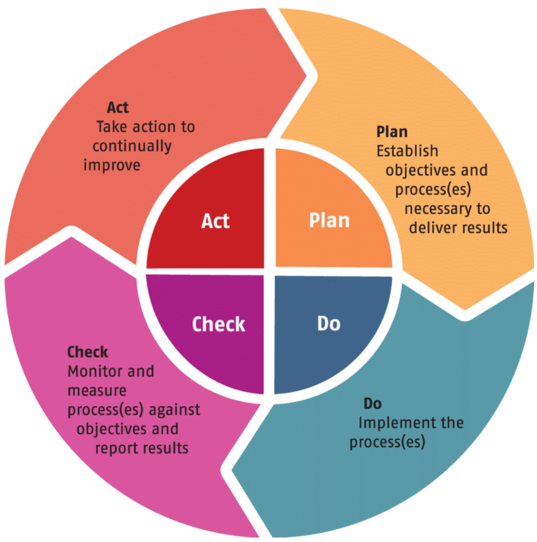

Figure 1.2: PDCA

The various tools that it uses to identify problems, analyze processes, and implement improvements effectively are the following:

1. **The 5 Whys**: it's a simple yet powerful problem-solving technique used to uncover the root cause of an issue. It involves repeatedly asking "Why?" (typically, five times, though more or fewer may be needed) until the fundamental cause of a problem is identified.

2. **Value Stream Mapping** (VSM): it is a great tool for visualizing how materials and information flow through a process.

3. **Standardized work**: it helps to determine where things might be slowing down or where there's waste. The goal is to create reliable and repeatable procedures that can lead to improvements. To do this effectively, the standards should come from the people who are actually doing the work every day. Operational models cannot remain static but must evolve and progress in line with the philosophy of continuous improvement that permeates daily business life. A production process is appropriately standardized when the documented experience is supplemented by tools like checklists, enabling supervisors to ensure tasks are executed correctly

4. **Gemba walks**: managers and supervisors take a stroll through the shop floor, or Gemba, to really see what's going on. By observing the work processes up close, they can pick up valuable insights into the real conditions workers face every day and the challenges they encounter.

1.2.3 Just In Time (JIT)

Just-In-Time (JIT) is a production methodology aimed at optimizing manufacturing efficiency by aligning production schedules directly with customer demands. The core philosophy of JIT is to produce the required quantity of goods at the exact time they are needed, thereby minimizing waste, reducing inventory levels, and improving overall operational efficiency. Originating from Toyota's production system in Japan, JIT has since been widely adopted across various industries, becoming a cornerstone of Lean Manufacturing.

The basis of the Toyota production system is the absolute elimination of waste. The two pillars needed to support the system are:

- Just-In-Time
- Automatization, or automation with a human touch

A company establishing this flow throughout can approach zero inventory. From the standpoint of production management, this is an ideal state. However, with a product made of thousands of parts, like the automobile, the number of processes involved is enormous. Obviously, it is extremely difficult to apply just-in-time to the production plan of every process in an orderly way. An upset in prediction, a mistake in the paperwork, defective products and rework, trouble with the equipment, absenteeism - the problems are countless. A problem early in the process al-ways results in a defective product later in the process. This will stop the production line or change a plan whether you like it or not. By disregarding such situations and only considering the production plan for each process, we would produce parts without regard to later processes. Waste would result- defective parts on one hand, huge inventories of parts not needed immediately on the other. This reduces both productivity and profitability. Even worse, there would be no distinction between normal and abnormal states on each assembly line. When there is a delay in rectifying an abnormal state, too many workers would make too many parts, a situation not quickly corrected. Therefore, to produce using just-in-time so that each pro cess receives the exact item needed, when it is needed, and in the quantity needed, conventional management methods do not work well.

1.3 The Seven Wastes (Muda) in Lean Manufacturing

The concept of Muda (waste) is central to Lean Manufacturing and was first articulated within the Toyota Production System (TPS). Taiichi Ohno, the architect of TPS, identified seven primary types of waste that organizations should strive to eliminate to improve efficiency and productivity:

1. **Overproduction**: it refers to the wasteful production of items that are not needed immediately. It is a concept from the Lean manufacturing system, which is a business philosophy that aims to reduce or eliminate wasteful practices in order to be more efficient. Producing more than needed, producing faster than necessary and holding excessive inventory cause overproduction. Just-in-time production increases productivity by minimizing the amount of inventory and raw materials available. In this way, production takes place in direct proportion with demand and the amount of excess stock produced is reduced. It is also possible to reduce the amount of excess and defective production by performing demand analysis and improving quality control

2. **Waiting**: it refers to wasted time due to delays in production. Time is lost when machines are not working at full capacity, processes are inefficient or resources are not managed properly. By eliminating these sources of delay, companies have the opportunity to reduce costs and increase efficiency. By using automation, you are able to automate tasks that normally require a lot of manual input or effort. It is possible to automate tasks, reduce waiting times and increase productivity. Also, streamlining existing processes determines step by step everything that needs to be implemented. This eliminates complexity and avoids wasted time

3. **Transportation**: moving materials involves shifting goods from one location to another, but this process doesn't actually add any value to the product itself. Because it doesn't enhance the final output, it ends up being an unnecessary expense for both the company and the customer. Paying for activities that don't improve the product just drives up operational costs without offering any extra benefits

4. **Overprocessing**: overprocessing is putting too much effort into an activity that does not add value. This includes unnecessary processes, unnecessary testing, excessive design, or other activities that do not directly assist the customer. Overprocessing wastes time, money and resources. This leads to

the introduction of poor-quality products or services. It also causes increased costs, longer lead times and reduced customer satisfaction. Identifying and eliminating all unnecessary steps that do not add value to the process prevents overprocessing. Also, regularly evaluating processes helps identify and eliminate overworked areas

5. **Inventory**: when too much stock is not used or sold, it is considered a waste of inventory. This occurs when the amount of stock exceeds current demand. It causes the stock not to be moved or sold. To avoid this, businesses should monitor their stock levels and adjust their orders accordingly to ensure they don't overstock or under-stock. Businesses should also explore inventory management solutions that can help them better track stock levels and order more efficiently

6. **Motion**: inefficient processes for collecting information, unnecessary movement for assembly or packaging, and excessive use of materials are examples of movement waste. Such wasteful activities not only add time and cost to the production process but also cause worker fatigue

7. **Defects**: waste of defective products can be reduced by implementing an effective quality control process.

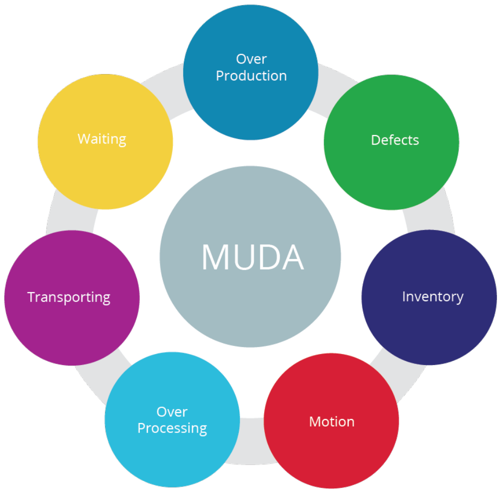

Figure 1.3: The 7 Wastes (MUDA)

To minimize Muda, organizations must adopt a continuous improvement mindset and em-ploy tools like Kaizen, 5S, and Just-In-Time (JIT). Identifying waste requires a deep under-standing of processes and a commitment to value creation. Techniques such as value stream mapping can help visualize and address areas where waste exists. By systematically addressing these seven forms of waste, companies can streamline their operations, enhance quality, and deliver value more efficiently to their customers, aligning with the Lean philosophy of "doing more with less."

1.4 Total Flow Management (TFM)

Total Flow Management is a Lean-based approach aimed at optimizing logistics and supply chain functions. It's designed to boost efficiency in both manufacturing and service environments. The main focus here is to build an internal pull system that helps create smooth workflows while cutting out non-value-added activities (NVAA). After we've simplified internal processes, we can then turn our attention downstream to enhance customer deliveries and also upstream to improve interactions with suppliers.

1.4.1 Internal logistics flow

One of the core pillars of the Total Flow Management (TFM) model is the internal logistics flow. Its primary challenge is to establish a streamlined movement of small individual containers within the production area and determine the most suitable containers to ensure both flexibility and productivity at the line-side. To achieve this, internal logistics must be organized to supply all necessary components in alignment with the cycle time of the production line. Another key objective of internal logistics flow is to create an information flow that originates from the actual customer order or replenishment requests. These orders (or customer demands) need to be quickly transformed into production orders and sent to the production area to facilitate the picking and delivery of components to the lines.

The improvement areas for internal logistics flow can be categorized as follows:

- Supermarket: Organizing picking areas efficiently to facilitate the flow of containers containing all required materials and components
- *Mizusumashi* (literally "water spider" – logistics transport operators): Ensuring the swift transport of containers to the line-side
- Synchronization: Initiating production, picking, and delivering required materials in a synchronized manner
- Leveling: Scheduling production orders effectively within the pacemaker process
- Pull-based Production Planning: Setting production capacity and calculating customer needs based on pull system principles

By addressing these areas, the internal logistics flow pillar supports the broader TFM model in achieving a seamless, synchronized, and efficient supply chain operation.

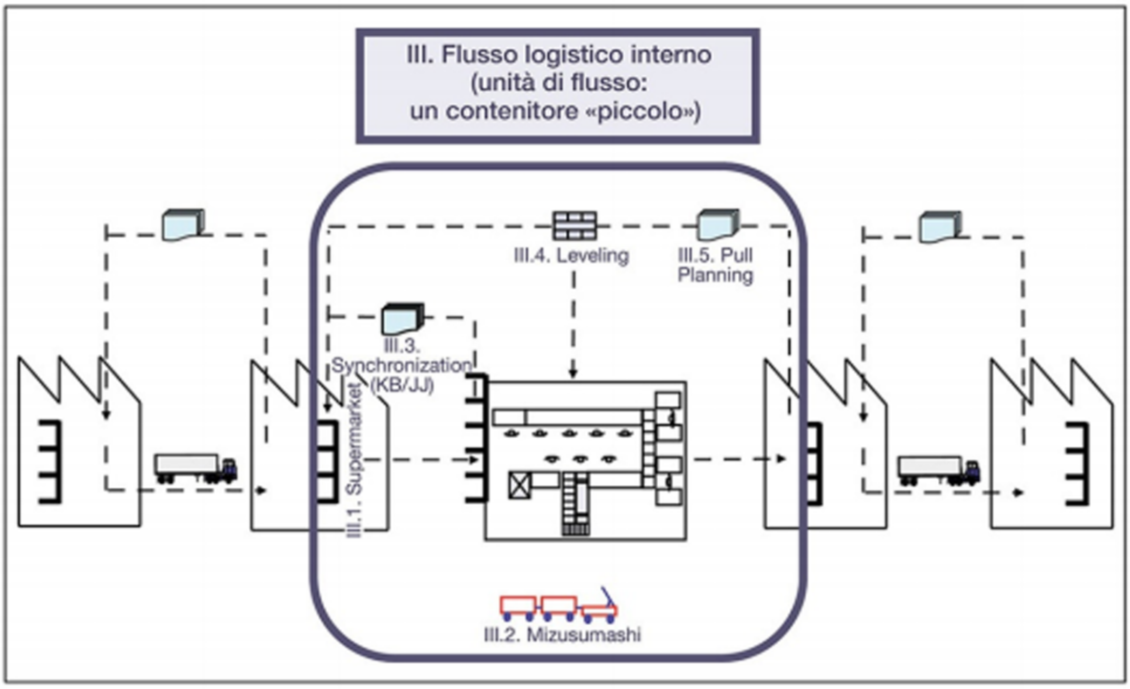

Figure 1.4: Integrated logistics and production flow [7]

Our main goal is to align with what our customers want, providing top-notch quality at the best possible price. To make this happen, we need to smoothly integrate logistics and production, ensuring we have both a "one-small-container flow" and a "one-piece flow" right on the shop floor.

Often, traditional logistics focuses on optimizing processes in isolation, which overlooks the real needs of production efficiency. Similarly, production departments often limit their improvements to existing logistics constraints, rarely exploring the concepts of production flow. This disjointed approach leads to various types of waste (Muda) in both production and logistics. The traditional logistics model is based on the following principles:

- Minimizing internal transportation by delivering large batches to production lines (usually once per shift)
- Reducing storage space requirements for incoming materials and work-in-progress through vertical stacking
- Using forklifts to handle pallet-sized containers
- Transferring unpacking or repacking tasks to production lines (e.g., delivering unopened boxes to the production line, leaving operators to open them)
- Planning large production orders to minimize changeover times and maximize efficiency

In contrast, flow-based logistics organization operates under different principles:

- Supplying containers appropriately sized for their use, maximizing production line efficiency and flexibility
- Establishing well-organized picking areas to deliver appropriately sized containers frequently and efficiently
- Using suitable transportation equipment to ensure timely delivery via standardized routes with fixed cycle times (e.g., a small train delivering supplies to stations along its route for one-hour operations)
- Collaborating with suppliers and customers to standardize container sizes (or managing all necessary repacking and unpacking) to deliver the right materials to the right place in the right quantity with the right presentation system
- Planning customer orders while balancing supplier orders to ensure alignment

The flow-based system represents a significant advancement in logistics efficiency, integrating logistics and production to achieve a fully optimized internal logistics cycle.
Forecasting, however, introduces inherent challenges:

- Demand forecasts are never entirely accurate, leading to discrepancies
- Actual production times differ from standard times, and defect rates vary
- Information on work-in-progress (WIP) inventory changes rapidly, outpacing the system's ability to maintain data reliability

While MRP systems aim to align forecasts with production and procurement orders, the fast-changing dynamics of real-world operations often lead to mismatches between planned and actual conditions. This is due to the inherent complexity and variability of the four M's (Manpower, Machines, Materials, and Methods).

A centralized system cannot maintain perfect synchronization because the performance of a push system will always depend on the specific context, whereas a pull system consistently delivers superior performance. A pull flow system does not rely on centralized scheduling. Instead, it starts with confirmed customer orders, which are either scheduled for production or retrieval, depending on the established customer service policy. Some components may be classified as make-to-order, while others are pick-to-order (produced for stock). These orders are sent to a single point within the supply chain. Material and component consumption begins at this point, triggering replenishment orders, which in turn generate further orders upstream in the supply chain. The mechanism is straightforward: the system responds to actual consumption rather than planned orders. This allows staff to focus on re-solving the issues causing the delays, while synchronization adjusts automatically. The pull flow system represents a new paradigm in supply chain management, offering an adaptive and efficient alternative to traditional push systems.

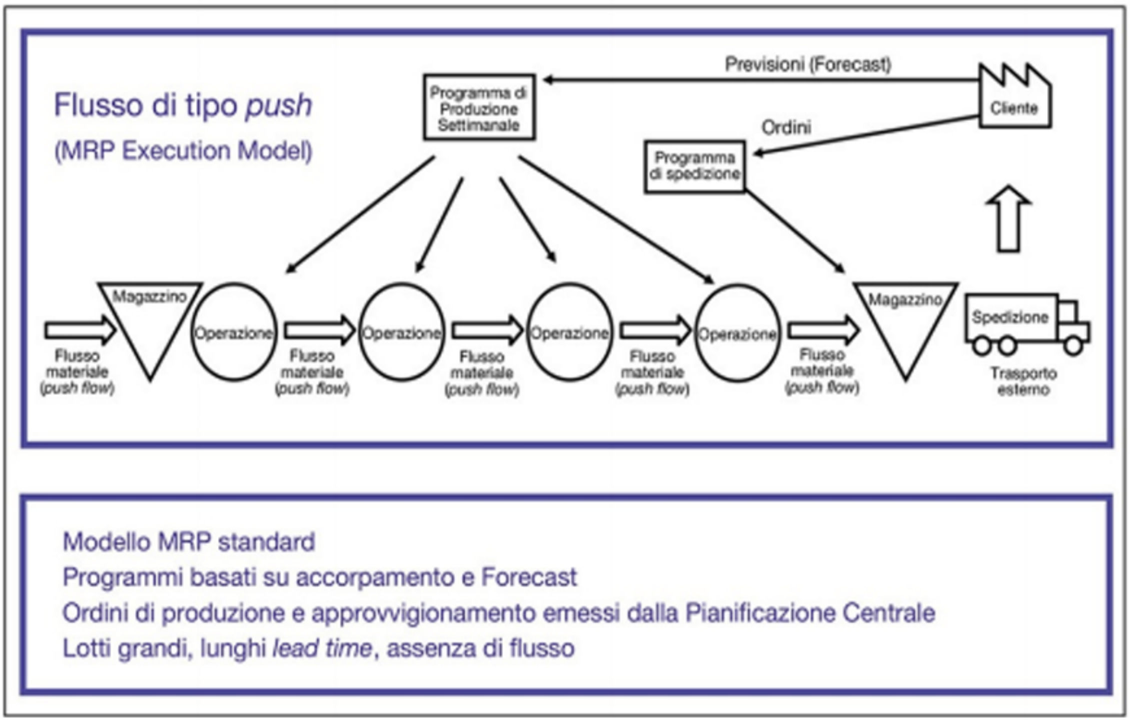

Figure 1.5: Push flow model [7]

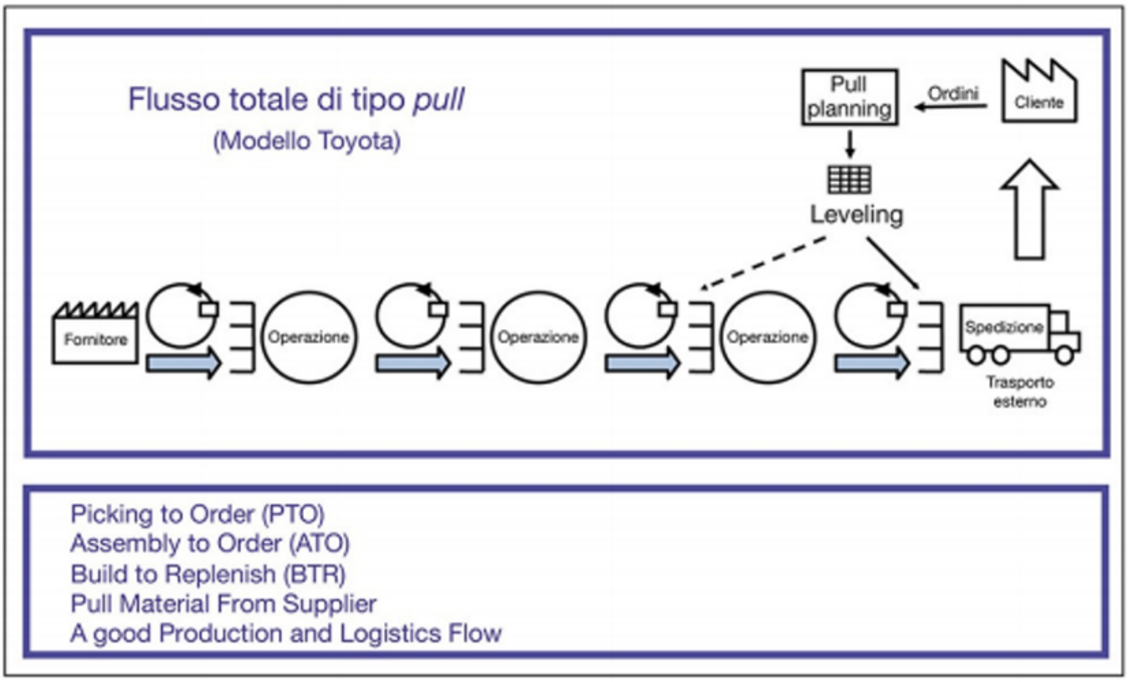

Figure 1.6: Pull flow model [7]

1.4.2 Mizusumashi

The first area of improvement in an internal logistics flow is represented by supermarkets. This term refers to the concept of having the same ease of picking products as when shopping in a supermarket. Customers select what they need without consulting a computer system or placing orders, as they would in a traditional warehouse. Goods are arranged in an organized and accessible manner, allowing operators to simply take what they require and move on to the next shelf.
The primary need is for straightforward storage to enable smooth flow while minimizing non-value-adding activities by logistics operators. These often include lengthy waiting times and slow, non-linear actions. For example, consider a flow container (such as a pallet) stored in a supermarket. The pallet is placed on a wheeled base, and its location must be immediately identifiable through Visual Management. The operator arrives with a small train, stops next to the pallet, transfers it onto their vehicle, proceeds to the line-side, stops, and places the pallet near the production operator (or in designated unloading areas). In some cases, they also remove an empty pallet on wheels, completing the supply process for the production line. This entire operation is managed by logistics operators known as *mizusumashi*.
Mizusumashi, the second area of improvement in internal logistics flow, are the key elements enabling its implementation. This Japanese term, meaning "water spider," was likely chosen for the agility of the insect. In logistics, a mizusumashi is an operator responsible for internal material transport. They follow a fixed, standardized cyclic route, delivering production orders (kanban) and managing the flow of containers. Their work is to move flow containers between storage areas and the production line. They follow a set routine, making their rounds every 20 to 60 minutes with regular movements. During this cycle, the mizusumashi stops at various points along their route to check for material requirements. They use a small train with sufficient capacity to serve all designated stations in their round, delivering information and materials to points along the path. The fixed cycle time of the mizusumashi, known as pitch time. If the mizusumashi moves one piece at a time, their pitch time would equal the cycle time. However, since they handle small containers, their pitch time is designed to move several containers to multiple usage points along the line-side of several production lines.
The customers in this system are the production line operators, who rely on a dependable logistics provider. The mizusumashi ensures a reliable and frequent supply by checking for additional material needs, removing empty containers, and clearing any waste generated by the process (reverse logistics). This system guarantees consistent and efficient material sup-ply, ensuring the smooth functioning of production lines.

The third area of improvement in internal logistics flow is synchronization. Synchronization refers to the coordination enabled by the information system used to signal the start of production, material picking, or delivery processes. The operator utilizing synchronization information is the mizusumashi, who identifies when a container needs to be moved to its required location and triggers the production of a specific item on the line. Synchronization can be successfully achieved using physical devices and later automated through an information system. An effective and efficient physical (visual) information system is essential, allowing users to quickly understand and react to changes.

Two primary methods for achieving synchronization are:

- Kanban logistics cycle
- Junjo logistics cycle

In a **Kanban cycle**, the mizusumashi checks for empty boxes at the line-side, each marked with a kanban card containing details such as component code and supermarket location (supplier). The mizusumashi collects the empty box and its card, returns to the supermarket, and retrieves a full, identical box for the next delivery cycle. This basic kanban logistics cycle may become more complex if production steps are included within the logistics cycle.

In a **Junjo cycle**, the mizusumashi receives a pick list containing components arranged in the sequence required by the operator (the mizusumashi's internal customer). The operator receives precisely what is needed for the next cycle, and this process repeats for subsequent cycles. Junjo, meaning "sequential delivery," has the advantage of reducing the size of the kanban supermarket. In this case, the line-side does not need dedicated space for multiple components, only the necessary space for the specific sequence.

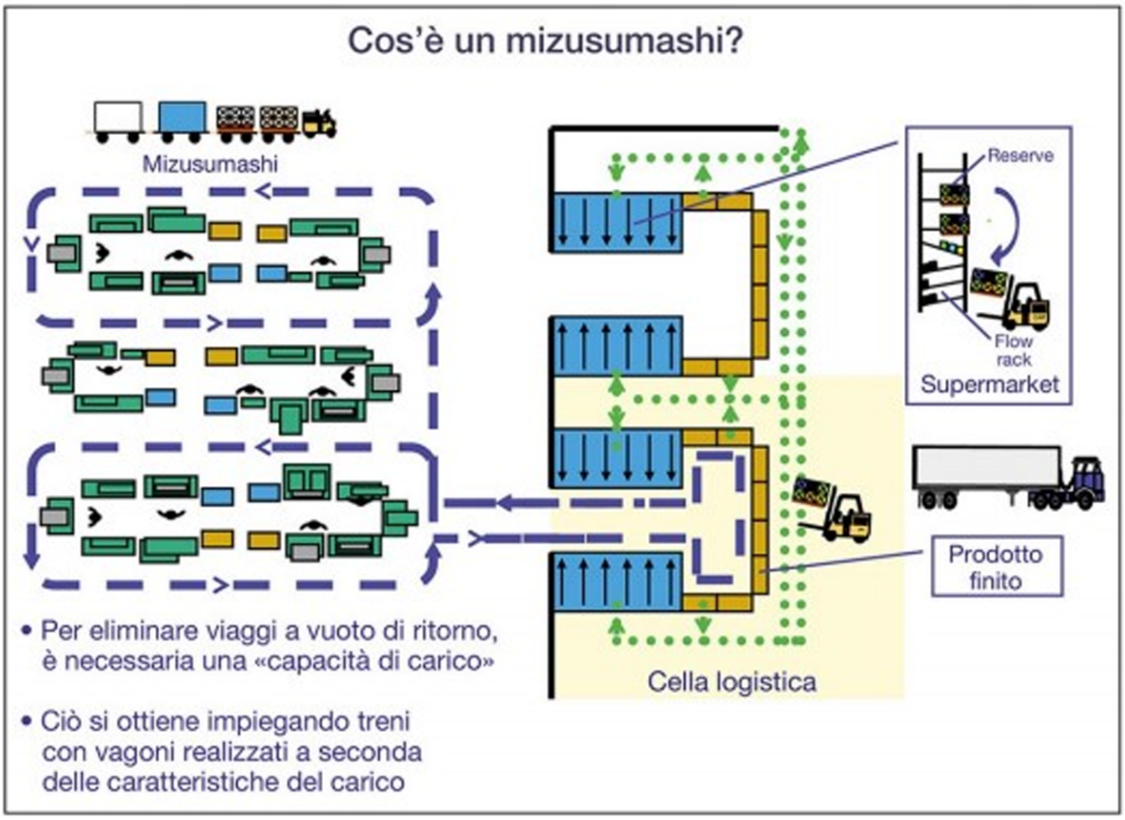

Figure 1.7: Mizusumashi standards path [7]

1.5 Tools and Techniques in Lean Production

Several tools and methodologies are used to implement Lean principles effectively. These are the main concepts that will be analyzed in the following chapters: the 5S system, Kan-ban, Value Stream Mapping (VSM), and Spaghetti Chart.

1.5.1 5S System

The 5S methodology is a fundamental component of Lean Manufacturing, originating in Ja-pan as a practical system for workplace organization and efficiency. The term "5S" refers to five Japanese words—*Seiri*, *Seiton*, *Seiso*, *Seiketsu*, and *Shitsuke*—that represent steps to establish and sustain a productive and efficient workplace. When implemented correctly, 5S not only enhances operational efficiency but also fosters a culture of discipline, safety, and continuous improvement.

Figure 1.8: 5S system

The 5S methodology was developed as part of the Toyota Production System (TPS) under the guidance of pioneers such as Taiichi Ohno and Shigeo Shingo. It aligns with Lean principles by eliminating waste (Muda), improving workflow, and creating a visual workplace where abnormalities are easily detectable. Each "S" represents a step in the process, contrib-uting to a structured, clutter-free, and safe working environment. The philosophy behind 5S is deeply rooted in Japanese culture, emphasizing respect for the workplace, attention to detail, and the discipline to maintain order consistently.

The Five Steps of 5S:

1. **Seiri** (Sort)

   The first step involves identifying and removing unnecessary items from the workplace. By distinguishing between what is needed and what is not, clutter is eliminated, and essential tools or materials are prioritized. The aim of Seiri is to reduce waste, improve focus, and free up valuable space. An example could be disposing obsolete equipment or tools that no longer serve a purpose in production

2. **Seiton** (Set in Order)

   This step focuses on organizing necessary items for easy access and efficient use. Every-thing should have a designated place, and the arrangement should be intuitive for workers. The goal of Seiton is to minimize time spent searching for tools and materials, implementing - for example - shadow boards for tools or labeled storage bins for raw materials

3. **Seiso** (Shine)

   The workplace is cleaned and inspected to ensure that equipment and tools are in optimal working condition. Cleanliness is maintained as a regular activity rather than an occasional effort with the aim of detecting abnormalities, preventing defects, and promoting a safe environment – for example - regularly cleaning machines to prevent buildup of dirt or residue that could lead to breakdowns

4. **Seiketsu** (Standardize)

   Standardization involves establishing consistent practices and procedures to maintain the gains achieved in the first three steps. Visual management tools such as checklists, diagrams, and signage are often used ensuring uniformity and make adherence to 5S principles easy for all employees. A common activity could be creating a daily cleaning and maintenance schedule visible to all team members, for example

5. **Shitsuke** (Sustain)

   The final step is about fostering a culture of discipline and continuous improvement. Employees are trained to internalize 5S principles and maintain them over the long-term preventing backsliding into old habits and ensure the longevity of 5S practices. So, it's important conducting regular audits and encouraging team members to suggest improvements

Adopting the 5S methodology offers a wide range of benefits, such as:

- Improved efficiency: organized workspaces reduce downtime and increase productivity

- Enhanced safety: a clean and orderly environment minimizes workplace accidents

- Reduced waste: eliminating unnecessary items and improving workflows decrease resource consumption

- Higher morale: employees take pride in their workspace, leading to greater job satisfaction

- Quality improvements: detecting and addressing abnormalities early enhances product quality

By systematically implementing and maintaining 5S, companies can achieve significant improvements in productivity, safety, and employee engagement. This approach not only enhances daily operations but also lays the foundation for broader Lean Manufacturing practices, creating a culture of continuous improvement and operational excellence.

1.5.2 Kanban

The Kanban system is designed to manage the supply of necessary parts in production by utilizing the movement of cards between different workstations, which indicate the actual consumption of components. This tool acts as an informational flow within production stag-es, enabling the timely replenishment of components or semi-finished goods between two interconnected stations. Kanban allows for real-time monitoring of actual consumption and avoids a "push" production model. Instead, every replenishment or production activity is driven by the reception of real-time information. Numerous scholars have explored Kanban techniques, adapting them to specific work con-texts. This practice can take various forms beyond the traditional physical card. For in-stance, it can involve the use of containers (the return of an empty container signifies a replenishment order) or spaces (an empty space signals the need for refilling). Kanban facilitates the application of Just-In-Time (JIT) production, triggered by customer orders, and serves as a key activity for adopting Lean Manufacturing principles.
Kanban cards flow from the final assembly station back to the initial upstream workstation. The primary benefit of this system is its ability to control inventory levels [8]. Tardif and Maaseidvaag([9])defined Kanban as "a mechanism for controlling and producing only what is strictly necessary in the right quantities and at the right time." Furthermore, Naufal et al.
([10])concluded that implementing a Kanban system can help reduce lead times in storage areas and inventory levels.
The kanban system determines the production quantities in every process. The primary benefit of the kanban system is to reduce overproduction; and its aim is to produce only what is ordered, when it is ordered, and in the quantities ordered.

In Japanese, the word "kanban" means "card" or "sign" and is the name given to the inventory control card used in a pull system. It is essentially a work order that also moves with the material. Each card or kanban identifies the part or subassembly unit and indicates where each came from and where each is going. Used this way, kanban acts as a system of information that integrates the plant, connects all processes one to another, and connects the en-tire value stream to the customer demand harmoniously.

Workers in one process go to the preceding process to withdraw the parts they need. They do this only in the quantities and at the time when the units are needed. The start of this withdrawal system begins with a customer order. This is called a pull system.

Supply info	Part info	Customer info
	Part # **52107**	User processes **Small parts DSG**
Raw material code **4" x 4' cants**	Description **3/8" board x 4'**	Storage locations **C-12**
Raw material location **Shed 1 - B6**	Quantity **400/skid**	Kanban #/Issue date **#4 - 3/18/95**

Figure 1.9: A Typical Kanban Card [11]

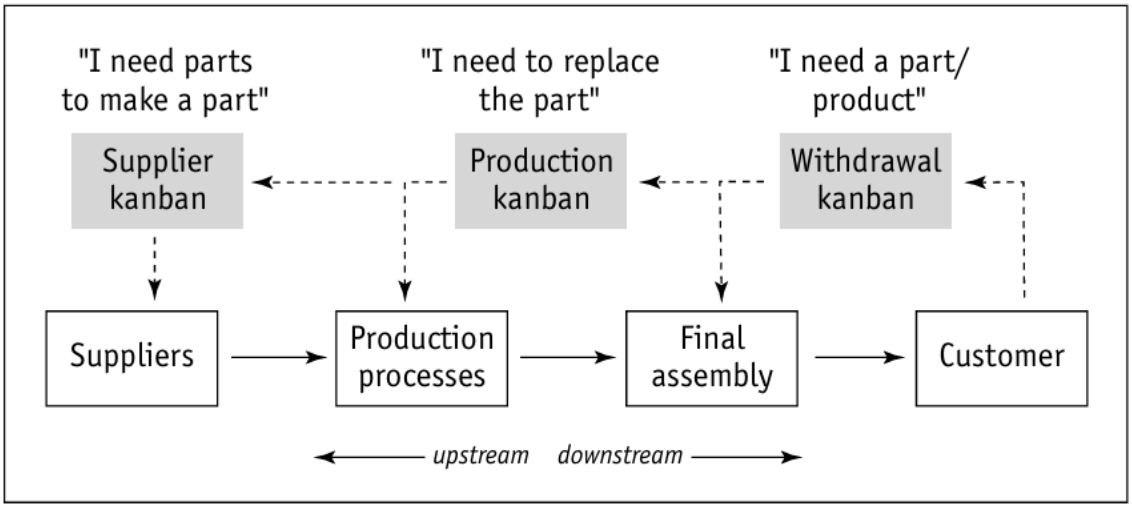

Figure 1.10: Pull Production with Kanban [11]

The pull system is based on the concept of a supermarket. In a supermarket, customers buy products already on the shelves and the shelves are replenished as customers remove the products from the shelf. Applied to lean production, this process reverses the large lot “push” method of producing products based on an estimate of expected sales. A pull system creates flexibility on the production floor so that exactly what has been ordered will be produced, when it is ordered, and only in the quantities ordered. In this way, it is possible to eliminate overproduction—the most critical of the seven deadly wastes. The ultimate conceptual goal is zero kanban, which eliminates work-in-process inventory. In other words, your customer order becomes the signal for a pure continuous flow. It is the ideal that the spirit of continuous improvement in a pull system always strives toward.

Kanban is an advanced visual control system and depends on the discipline and understanding that grow from implementing the 5S. The steps toward creating a visual workplace—beginning with 5S to put the workplace in order, establish visual displays, and support continuous improvements (which are initiated by each and every operator)—will be an important foundation for your pull system implementation.

Kanban will help your company:

- Eliminate overproduction: the # 1 waste
- Increase flexibility to respond to customer demand
- Find simple, visual, production instructions
- Eliminate unnecessary WIP inventory
- Uncover hidden waste in your process

The kanban system is based on an inventory management system called reordering point method. This is a statistical method that allows factories to reorder the same amount of parts or products each time. When inventory drops to a certain level—the reorder point—a new order is made to replace the used inventory. The reordering point method can be automated easily and it keeps inventory management costs down by reducing clerical work. However, it does not pay attention to changes in demand. In fact, this method is unsuitable where sharp fluctuations in demand exist.

Kanban cards will vary to serve the purpose for which they are intended. Ideally, they will be as thorough as possible and include the following kinds of information:

- The material, part, subassembly, or assembly number
- A description with a drawing or photo, if possible
- The previous process—where did it come from?
- The next process—where does it go?
- The internal or external supplying process (origin)
- The customer or factory order number
- What, when, and how much to withdraw
- What, when, and how much to make

Kanban cards are usually kept in plastic sleeves to protect them from dirt or tearing, which allows them to be read and handled easily and used repeatedly. They are attached to standardized con trainers that hold the parts to be withdrawn. One card can represent multiple products in one container or in multiple containers to correspond to a single production order.

1.5.3 Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is an important lean methodology that helps you visualize and evaluate the entire series of activities—both helpful and unhelpful—needed to turn raw materials into a final product or service for a customer. This approach also looks at how materials move and how information flows throughout the process. VSM is a great tool for spotting inefficiencies and methodically cutting out waste. It was first introduced by Toyota as part of the Toyota Production System, where it's known as a material and information flow diagram. Since then, it has been widely accepted to improve processes. The mapping process usually kicks off with a current state map, which accurately shows how materials are moving and how information is exchanged in a specific value stream. After that, a future state map is created to outline a better, more efficient version of the process.
By regularly using VSM, teams can sharpen their skills in separating essential steps in a process from those that are redundant or wasteful, promoting a culture of continuous improvement. While it was initially designed for lean manufacturing, this method has shown to be very effective across many industries, proving its flexibility in optimizing workflows and boosting operational efficiency [12].

The **Current State VSM** is a great way to visualize your team's current workflow. It helps you dig into the data to determine inefficiencies and waste, allowing for improvements that boost productivity.

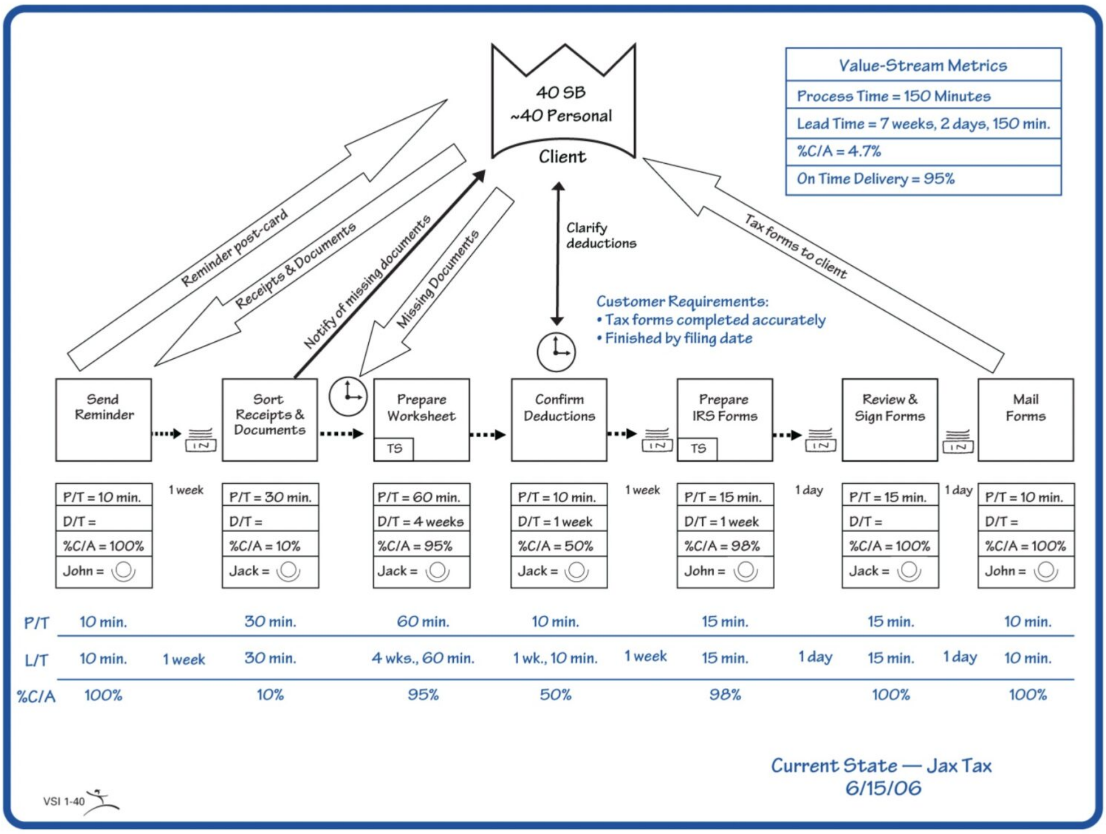

Figure 1.11: Current-State Value Stream Map

The **Future State VSM** is all about imagining how your process can function at its best. This stage lets you skip the usual improvement cycle and jump right into creating innovative and revolutionary solutions.
The goal here is to paint a picture of what your ideal future state looks like, using the gaps between where you are now and where you want to be to determine areas for improvement. While it's important to keep a balanced view of key elements on your map—like customers, suppliers, value creation, and oversight—there's a lot of room to be flexible in how you tackle this phase.

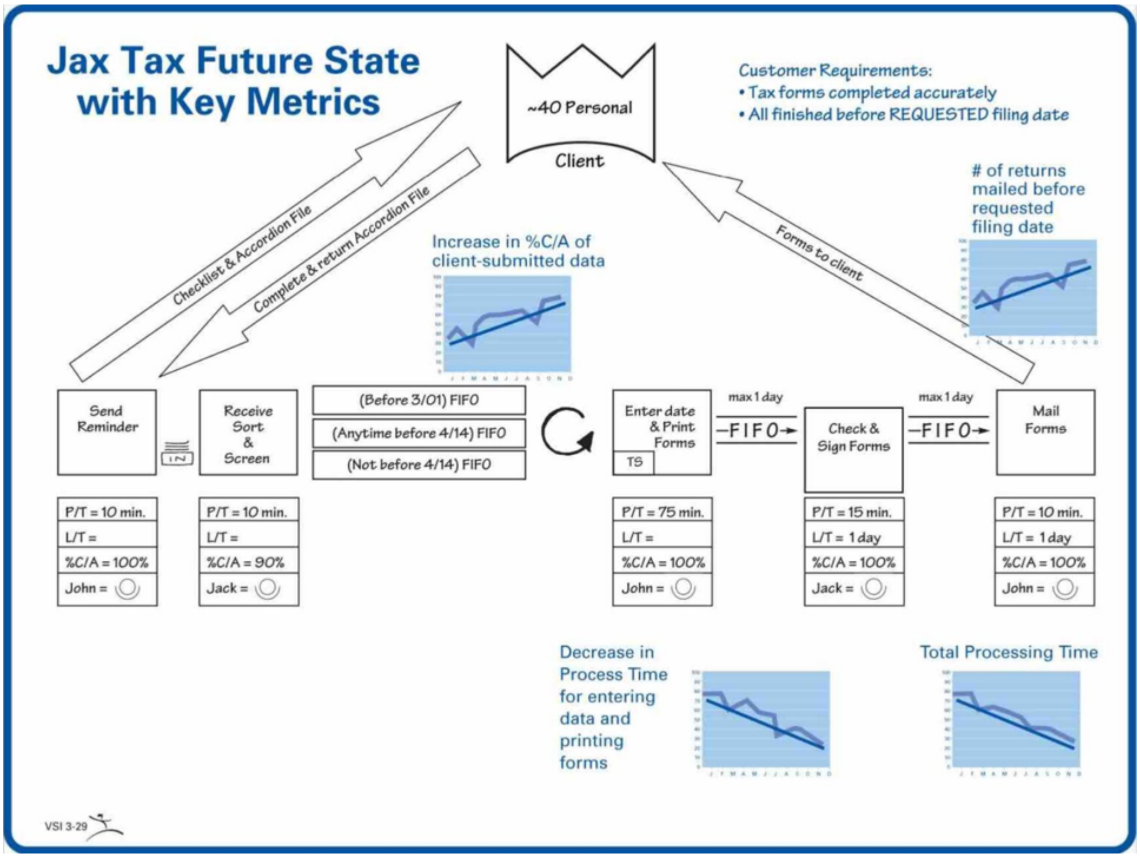

Figure 1.12: Future-State Value Stream Map

Basically, the **current-state map** gives everyone involved in the value stream a clear view of how each step adds value for the customer. It includes both material and information flows, helping to emphasize where improvements can be made. On the other hand, the **future-state map** outlines a shared vision of how things will work after those enhancements, serving as a strategic strategy for the changes ahead.

The main goal of current state mapping is to understand the full flow from start to finish, rather than just creating a determine accurate representation. Meanwhile, future state mapping focuses on painting a picture of the ideal version of the improved value stream.

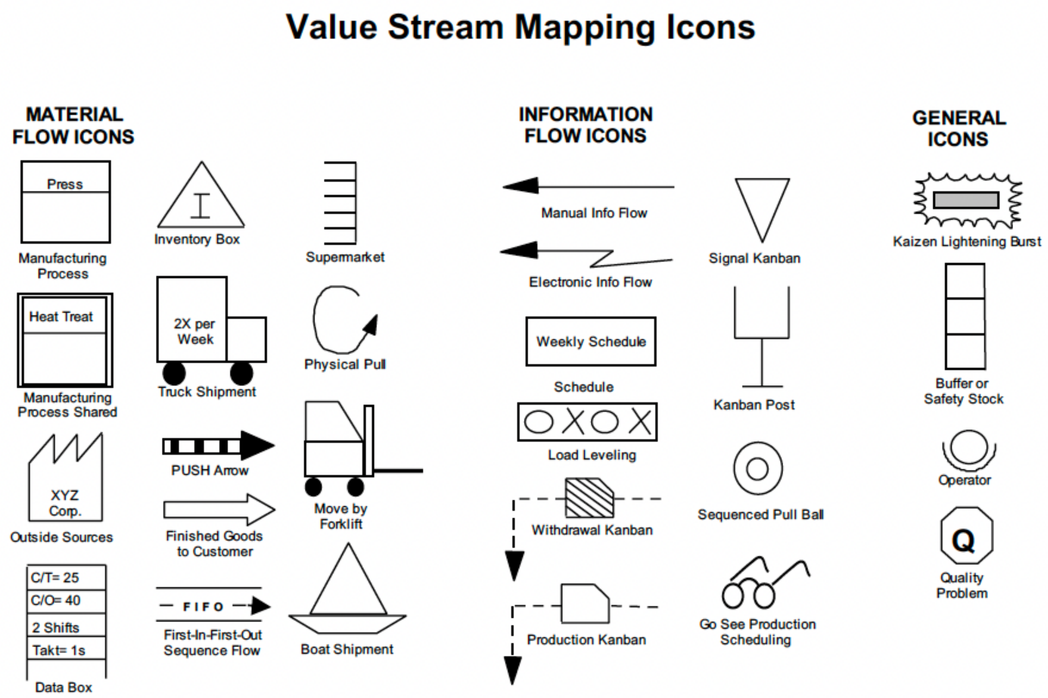

Figure 1.13: Value Stream Mapping Icons

1.5.4 Spaghetti Chart

Another valuable tool for use in manufacturing production plants is the “Spaghetti Chart.” The term refers to a Lean Manufacturing technique designed to highlight various pieces of information related to transport flows and a company’s layout. This method enables the creation of a mapping system aimed at improving and optimizing performance by ensuring that the physical arrangement of equipment, workstations, warehouse stock, and the movements performed by workers are configured for maximum efficiency. The focus of this technique lies in identifying the costs incurred due to the constant movement of goods, people, and tools within the facility. To implement this mapping effectively, a logistical analysis of the production environment must be conducted, tracing all types of movements that materials and personnel undergo using specific lines. The final result is a map where each type of movement is represented by a distinct broken line, clearly outlining the internal movement flows.

Once the diagram of the entire facility is complete, it becomes possible to make informed decisions to optimize production flows by eliminating unnecessary movements and inefficiencies. The goal is to minimize internal routes and intersections between flows/lines to en-sure a simpler layout, enabling production activities to become faster, more straightforward, and ”leaner.”

In their study on optimizing plant layouts in a manufacturing context, Goyal and Verma([13])emphasized the significant role of correctly applying the Spaghetti Chart in reducing material handling distances and associated transportation costs (we’ll see it in detail in the following chapters). They further highlighted that simply relocating certain workstations could reclaim previously wasted space.

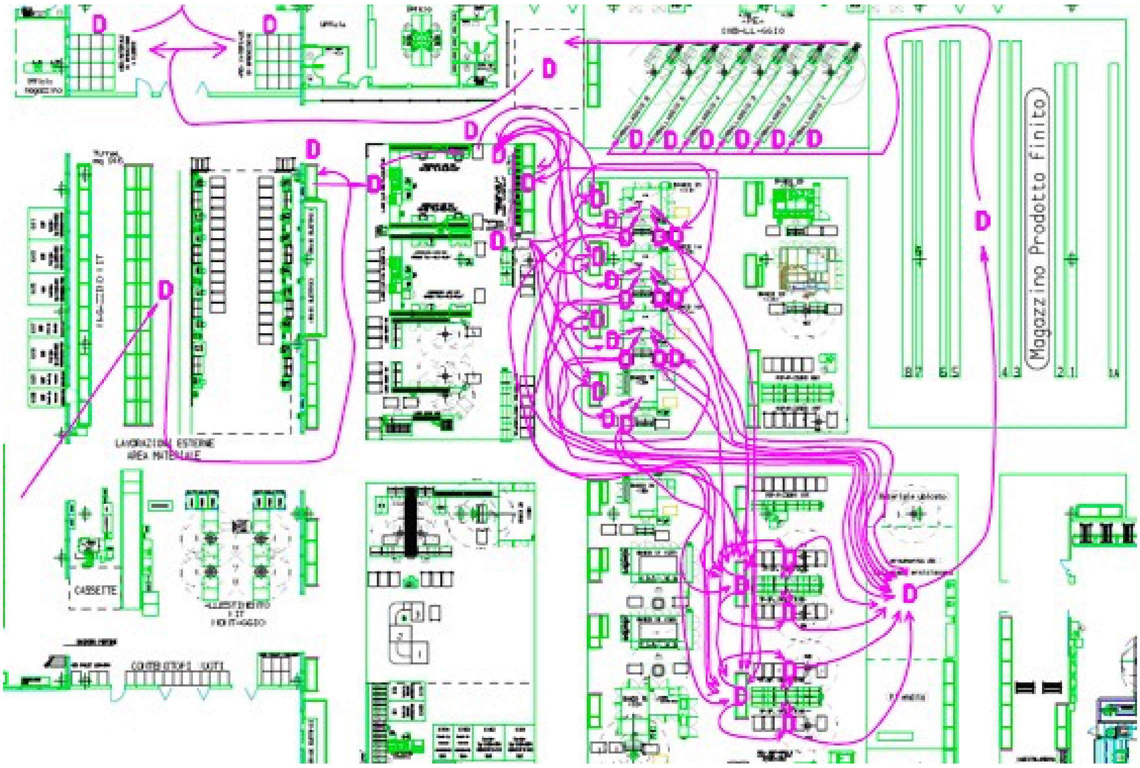

Figure 1.14: Spaghetti Chart [14]

1.6 Benefits of Lean Production

Lean Production isn't just about saving a few bucks and running things more smoothly. It's about creating a vibe of excellence, keeping things fresh and innovative, and making sure we're doing our part for the planet. When companies get on board with Lean, they find a sweet spot between getting things done quickly, making top-notch products, and keeping customers happy. That's how they can stay successful in a tough, ever-changing marketplace. Through its application, Lean Production proves to be not just a methodology but a strategic advantage in the modern industrial land-scape.

In today's fast-paced business world, being responsive and efficient is absolutely critical for success. That's where Lean Management steps in as a powerful strategy for organizations eager to lead the way. By focusing on cutting down waste and encouraging constant improvement, Lean Management helps businesses adapt quickly to changing customer needs, enhance the quality of their products and services, and reduce operational costs. Plus, Lean promotes a culture where employees feel engaged and enabled, encouraging creativity and teamwork—two essential ingredients for long-term success in today's competitive environment [15].

At the core of Lean Management is a commitment to customer satisfaction and loyalty. By focusing on providing real value to customers, this method enables businesses to better understand and meet their customers' needs and expectations. As a result, they can improve the quality of their products and services, deliver them faster, and do so at a lower cost. This continuous improvement not only enhances what they offer but also drives up customer satisfaction, giving them a essential edge in today's competitive business environment.

2 Company Overview: Tenneco Inc. in Chivasso

The Tenneco plant in Chivasso (TO), where the thesis project was carried out, represents a medium-to-large-scale facility, adding a layer of interest to the study. At Tenneco, production operates continuously, akin to major multinational companies in the automotive sector. However, the plant does not have access to the same financial resources or the extensive movement spaces typical of larger corporations. The constant supply to production lines, constrained by limited available space, combined with the complexity arising from production diversification, makes this work unique. Its application offers a practical and scientifically relevant solution.

2.1 History and brief introduction

Tenneco, based in Lake Forest, Illinois, is a major player in the automotive industry, standing out as one of the top designers, manufacturers, and distributors of both original equipment and aftermarket products. In 2023, the company reported an impressive revenue of $18.9 billion and employs around 71,000 people at more than 300 locations around the globe. Tenneco operates through four key business groups: Motorparts, Ride Performance, Clean Air, and Powertrain. These groups focus on delivering innovative solutions for a wide variety of markets, such as light vehicles, commercial trucks, industrial off-road equipment, and aftermarket parts.

Figure 2.1: Company Logo [16]

Tenneco became its own company back in 1999 when it split off from a larger multinational that operated in several different areas, including shipbuilding, packaging, agricultural machinery, construction equipment, gas transport, chemicals, and automotive. Since the 1980s, the organization has gone through a number of changes, like public offerings, divestitures, acquisitions, and mergers. This process gradually left Tenneco Automotive as the main focus of the original company. Today, it's this commitment to automotive manufacturing that truly defines Tenneco's identity. About 19 years ago, in 2005, Tenneco officially adopted its current name to better reflect its image in the global marketplace.
In order to keep up with the rising demand for light vehicles and explore new market segments, Tenneco massively expanded its international presence in the early 2000s, quickly becoming one of the key automotive suppliers in China. At the same time, the company worked on enhancing its engineering and manufacturing capabilities around the world, making a name for itself as a leader in developing clean

air technologies that help its clients meet strict emission control standards. Tenneco was one of the first to introduce diesel filters to the European market during that time and continues to lead the way with innovative after-treatment solutions for both gasoline and diesel engines. Furthermore, the company's advances in ride performance technology have contributed to better comfort, enhanced performance, and control, helping differentiate its customers' vehicles. In 2018 Tenneco acquired the American multinational Federal-Mogul, also a global leader in automotive components, thereby doubling its size and expanding into additional global markets. Today, Tenneco proudly manages over 30 of the most well-known and respected automotive brands.

The research took place at the facility in Chivasso, which is part of the Powertrain division and, prior to being acquired by the American giant in 2018, was a Federal-Mogul manufacturing facility. Today, the plant is known as "Federal-Mogul Powertrain – Tenneco Group" and is part of one of the many existing business units, named Sealing and Gasket, as its main business is focused on seals. Tenneco's Powertrain group designs, develops, and manufactures original equipment components and innovative technologies to help engine designers meet customer, regulatory, and market requirements, which are becoming increasingly demanding in every region of the world. Globally, Tenneco operates 21 technical research and development centers and 144 manufacturing plants. Specifically, the Powertrain sector includes 14 technology centers and 97 production facilities, including the Chivasso plant.
The Chivasso facility is considered a "global" reality: despite being medium-sized, with around 150 employees, it creates a family-like and welcoming atmosphere. At the same time, it fully embodies the multinational dimension, due to weekly visits from foreign representatives of major international companies who check the product manufacturing procedures, as well as the company's policy requiring daily interactions with the production line, fostering a broader international perspective.

Figure 2.2: Tenneco Plant in Chivasso (TO)

We demonstrate commitment to customer success through advanced technologies, quality products and powerful brands. We are prepared to support our diverse mix of customers anywhere in the world with our strategically located engineering, manufacturing and distribution footprint [16]

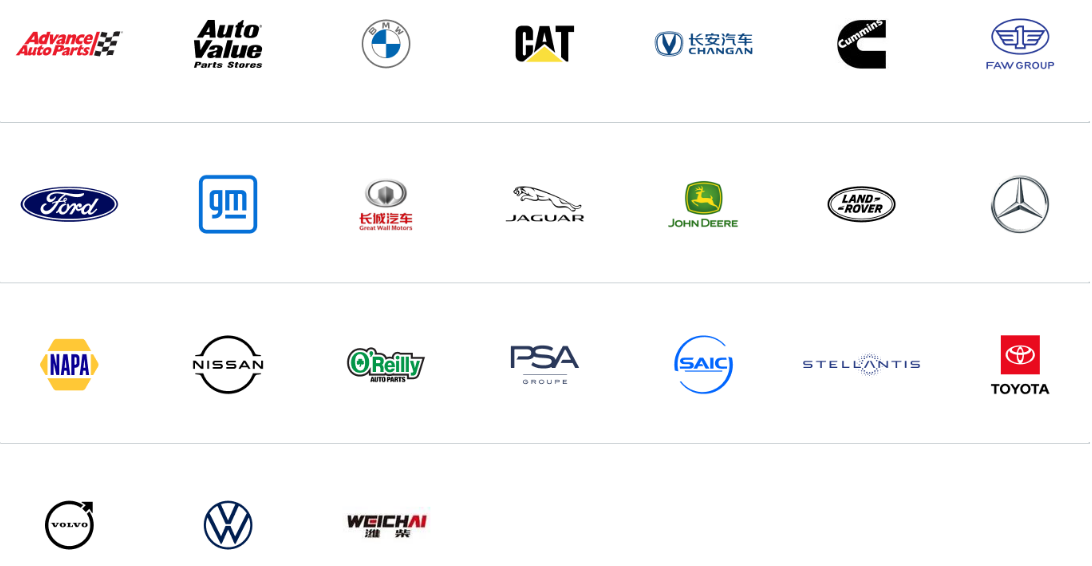

Figure 2.3: Serving OE and Aftermarket Customers

With more than 63,000 innovators spread across 200+ locations worldwide, Team Tenneco is redefining the automotive landscape. Encompassing 30+ global automotive brands (15 of which have century long legacies), we do more than talk -we Get Stuff Done and execute to win.
Our team spans continents, cultures, and disciplines, united by a drive to push boundaries. From engineering marvels to marketing breakthroughs, we offer careers that accelerate ambition.

Figure 2.4: Locations Worldwide

2.2 The four main business groups

With a revenue of $18.9 billion in 2023 and a workforce of approximately 71,000 employees across more than 300 sites worldwide, the company operates through four main business groups: Motorparts, Ride Performance, Clean Air, and Powertrain.

2.2.1 Clean air

As leaders in emission control solutions, Team Tenneco is committed to designing, engineering, and manufacturing advanced systems that cater to the transportation sector, including passenger cars, commercial vehicles, and off-highway equipment. Our innovative technologies do more than just meet the standards for fuel efficiency, emissions reduction, and sound quality; they consistently push the boundaries, as we actively shape the future of sustainable mobility rather than merely responding to it. In the ever-changing landscape of global emissions regulations and the increasing demand for vehicle efficiency, Tenneco's Clean Air division stands out, providing solutions that set the standards for performance, efficiency, and environmental responsibility. Our engineering expertise is evident in three key areas: after-treatment systems, energy recovery, and sound engineering.

- After-treatment: We are reliable partners for global engine manufacturers facing stringent emissions regulations like Euro 6d, Euro 7, China 6, and Bharat 6. Our advanced after-treatment technologies are designed not just to reduce pollutants; they eliminate them completely.

- Energy Recovery: We transform waste into valuable resources. Our Clean Air technologies improve vehicle efficiency by converting waste into usable energy.

- Sound Engineering: From the thrilling roar of a sports car to the quiet elegance of a luxury sedan, we are the acoustic designers behind many cherished vehicles. Our state-of-the-art exhaust systems not only aim to reduce noise but also to create a unique acoustic signature for each brand.

2.2.2 Powertrain

Our Powertrain division is focused on innovation and providing cutting-edge engine components and technologies. The Tenneco team utilizes various fuel options to assist our global customers in meeting strict regulations and overcoming market challenges, ensuring they maintain optimal performance and strengthening our commitment to being the most reliable partner and leading manufacturer in the industry [17].
Tenneco's Powertrain team focuses on creating, developing, and producing original equipment components and technologies that help engine designers tackle major challenges, such as strict regulations and high market demands globally.

We work with a diverse range of fuel types, including gasoline, diesel, alternative fuels, and hybrid systems. Our cutting-edge systems and specialized coatings play a crucial role in reducing emissions, enhancing fuel efficiency, and pushing the boundaries of engine design.

2.2.3 Performance Solutions

The Performance Solutions division at Tenneco brings together a group of leading companies, all working alongside top global manufacturers. Our team designs, innovates, and implements advanced systems that set new standards in security, user experience, and operational excellence. As market demands grow, we enable clients not just to keep up but to excel in their industries through transformative innovations.

This division enhances mobility systems around the globe, covering personal vehicles, heavy-duty machinery, industrial equipment, rail systems, and aviation technologies. Our Original Equipment network collaborates closely with leading manufacturers to improve the quality of journeys for both operators and passengers. Through innovative engineering, we push beyond traditional limits of vehicle dynamics and control, consistently exceeding rigorous industry standards for operational performance, passenger comfort, and accident prevention.

In addition, our Protective Systems unit develops safeguards that protect essential components from thermal stress, wear, and signal interference. We understand that optimal performance relies on strong defense mechanisms as a foundation, ensuring lasting reliability in challenging environments.

2.2.4 Driv

DRiV functions through a network of more than 30 well-respected aftermarket automotive brands known for their dependability in the industry. Tenneco's committed team is focused on delivering high-quality vehicle parts aimed at enhancing performance and longevity across various driving conditions—whether tackling rough roads, covering long distances, or managing everyday commutes. This mission is in line with the organization's primary goal: to establish itself as the most trustworthy partner and leading supplier in the automotive aftermarket, emphasizing excellence and reliability in all facets of its operations.

2.3 Production departments in Chivasso (TO)

The Tenneco Plant in Chivasso (TO), where I conducted my thesis project, is part of the Powertrain Business Group and it consists of different production departments, each specialized in a specific work cycle:

- **Gasket**: production of static steel seals

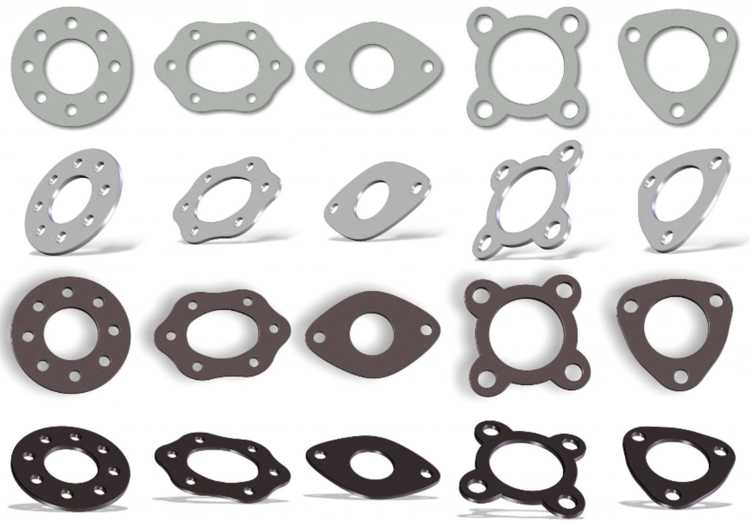

Figure 2.5: Examples of Gasket

- **EMG**: an acronym for "Elastomeric Metal Gaskets," which refers to elastomeric metal seals. This type of seal is produced by combining rubber, metal, and fibers with steel, creating a component that merges the durability of metal with the flexibility and elasticity of rubber

Figure 2.6: Example of EMG

- **Unipiston**: production of seals for automatic transmissions. Seals, also known as "lip seals" or "sealing rings," are devices used to seal rotating mechanical components, such as crankshafts or gears, preventing fluid leakage (such as oil or grease) and protecting against contaminants like dust and dirt. A key feature of the seals produced in the Unipiston department is the use of a high-modulus elastomer, which increases the application pressure

Figure 2.7: Example of sealing ring

- **Dynamic Seal**: production of dynamic seals made from rubber and PTFE (polytetra-fluoroethylene) for crankshafts. Dynamic seals are designed for applications where relative movement occurs between components, such as in rotating shafts or sliding pistons. The materials used for these seals must be resistant to wear, pressure, temperature, and chemicals

Figure 2.8: Example of dynamic seal

- **Heat Shield (HS)**: production of heat shields for engines. Due to the large amounts of heat emitted by engines, heat shields are mounted on thermal engines to protect components and the bodywork from potential heat damage. These shields are typically made of aluminum or steel, with an insulating material, such as fiberglass, inside

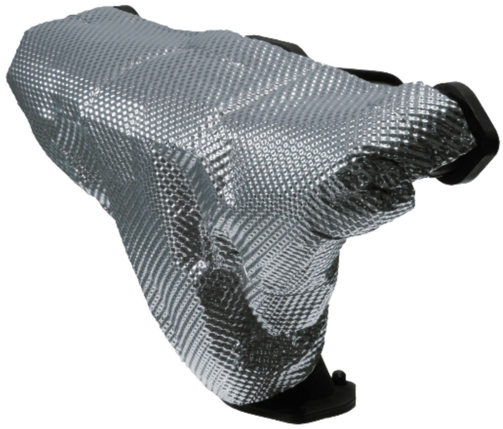

Figure 2.9: Example of Heat Shield

- **Tooling**: a department where operators are responsible for setting up and maintaining various molds
- **Maintenance**: a department responsible for various types of maintenance work, including electrical, mechanical, and hydraulic interventions
- **Logistics**: this area is divided into two distinct zones dedicated to the reception and shipment of goods

In this section, we will not delve into the details of the design process and the production processes. Instead, we will focus on analyzing and providing an overview of the macroscopic division of the areas involved in the thesis project.

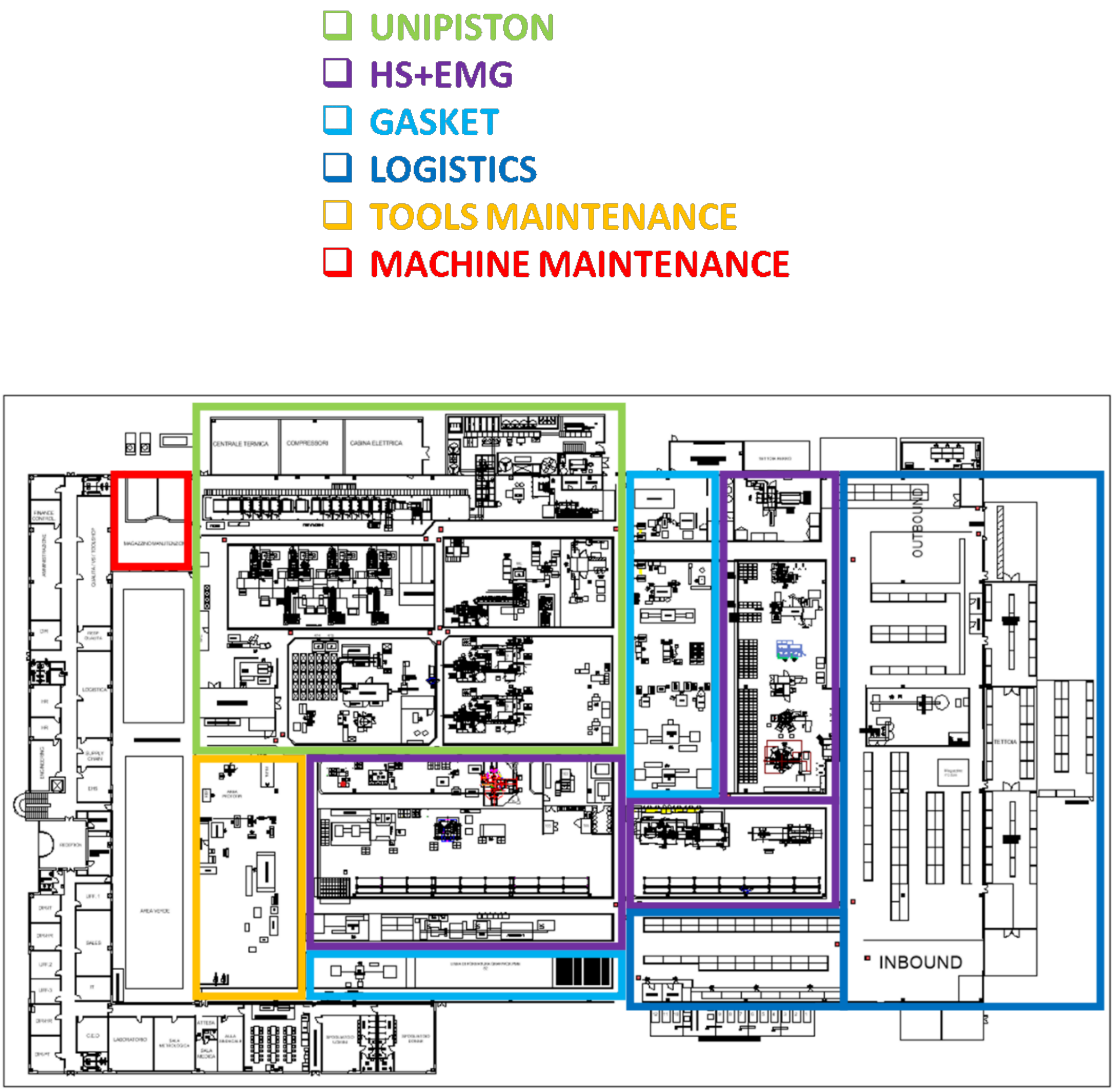

Figure 2.10: Production departments in Chivasso (TO)

3 Reorganization of Warehouse Goods: FIFO System Implementation

3.1 Introduction

This chapter is dedicated to the analysis of a critical aspect within the logistics-production cycle of a manufacturing company: the organization of the goods receiving warehouse. This area plays a strategic role in the management of industrial operations, as it constitutes the primary node for the storage of raw materials and components destined for the supply of production lines. In contexts characterized by high processing volumes and large finished products, as in the case study under examination, warehouse efficiency translates directly into a reduction in operational bottlenecks and an improvement in the flow of materials to the production areas.
The importance of a rational warehouse design becomes particularly evident where systemic inefficiencies are found, resulting from a chaotic arrangement of articles and a lack of logical criteria in stock allocation. In this specific case, the previous configuration of the warehouse generated a significant waste of time and economic resources, with operators engaged in NVVA (Non Value Added Activities) - such as searching for materials at uncoded shelves - for more than thirty minutes per pick. This criticality, multiplied by the high frequency of daily picking operations, had negative repercussions on the entire value chain, including delays in line supply, increased operating costs and reduced overall productivity.

The objective of the project illustrated in this chapter is to implement an optimized layout, based on lean manufacturing and visual management principles, aimed at minimizing material search and picking times, and eliminating waste due to unnecessary handling and spatial disorganization. Through a structured methodological approach for the categorization of articles according to rotation and value, the definition of dedicated zones according to criteria of affinity of use, and the implementation of a standardized identification system, a systemic reconfiguration of the warehouse was pursued. In particular, the chapter will delve into:

1. The diagnosis of pre-existing criticalities, with a focus on efficiency losses quantified through metrics such as average picking times, frequency of movements and costs induced by production delays;

2. The design of the new layout, based on optimized slotting models consistent with material flows to the lines;

3. The evaluation of the expected impacts, in terms of reduced cycle times, reduced logistics costs and improved service to downstream production stages.

The results show how rigorous warehouse planning, combined with continuous monitoring through dedicated KPIs, can transform an area traditionally perceived as 'low value' into a strategic driver for operational efficiency and supply chain resilience.

3.2 Inbound Area and Goods Receiving Process

This chapter focuses on the structural and functional analysis of the goods reception area at the Tenneco plant in Chivasso (TO), a critical node for the management of supplies in the context of industrial processes. The investigation starts from an examination of the initial logistic flow, characterized by an acceptance phase that provides for the separation of goods into two macro-categories: raw materials and components in free pass - immediately available for production - and those in quarantine, subject to quality or documentary checks before integration into the production cycle.

Once the materials have passed the verification phase, they are allocated to the RM (Raw Materials) warehouse, structured in 666 locations distributed along seven rows identified by the letters ‘M’, ‘Q’, ‘V’, ‘W’, ‘X’, ‘Y’ and ‘Z’. As illustrated in Figure 3.1 - representing the orthogonal projection on a horizontal plane of the warehouse - the infrastructure consists of traditional standardized cell shelving (dimensions 2700 × 1200 mm), designed to accommodate up to three EUR pallets (1200 × 800 mm) per storage unit. The racking, developed vertically on four levels, optimizes the use of space in height, ensuring an overall capacity consistent with the volumes handled by the plant.

The current configuration of the RM warehouse reflects well-established criteria of spatial organization, but requires in-depth analysis to assess its efficiency in relation to the company’s production dynamics. In particular, the layout of the rows, the standardization of the cells and the vertical hierarchy of the compartments pose critical questions in terms of accessibility of materials, picking times and operational flexibility, central themes for the optimization of logistical processes in high-intensity industrial contexts.

This study aims to provide a technical baseline to understand the potential and criticalities of the current set-up, with the objective of identifying improvement solutions aligned to the principles of Industrial Process Engineering. The detailed analysis of geometries, storage capacities and material flows will be the premise for subsequent interventions aimed at reducing bottlenecks, increasing traceability and integrating advanced stock management logics. There is also a finished goods warehouse, which is similar in size to the raw materials warehouse, but which was not included accurately in the analysis of this paper, as a business problem was found mainly in the reception of goods, efficient storage of shelf material and line replenishment. Currently, the management of line replenishment and related storage activities do not best follow the logic of tense flow, but rather a management that aims at responding to circumstances as they occur, rather than preventing their occurrence. In fact, a study of the actual utilization of the components on the line is absent, as well as any waste that is generated and which leads to a reduction in the physical stock of parts. In the company, we rely heavily on the reference of the bill of materials and the ability of the personnel to filter realistic information from implausible ones, going to check personally to assess certain criticalities.

In addition, it is good to avoid unnecessary or excessive movements for the operators, a problem that currently also occurs due to the physical distance between the production lines and the RM warehouse. As there is no structured management and allocation of high and low rotating components, it can happen that the time required to search, collect and deliver an item to the lines is excessive and inefficient. The purpose of this chapter is to address the issues of Lean Manufacturing from a

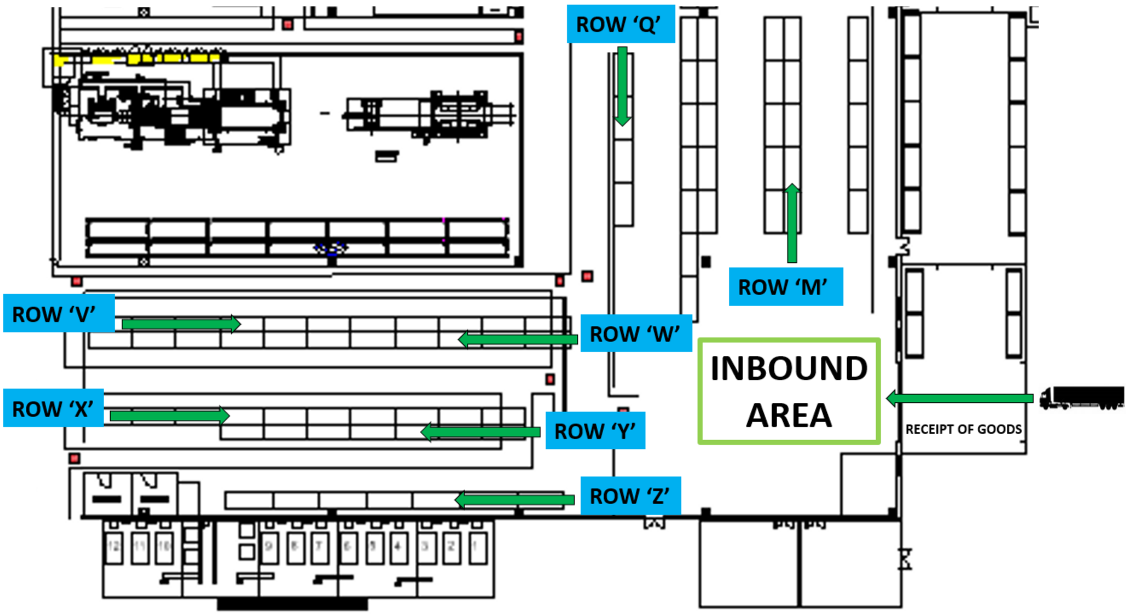

Figure 3.1: Inbound Area and Raw Materials Warehouse

business case. We will focus, in particular, on the study, optimization and dimensioning of a warehouse for raw materials managed according to a FIFO (First-In-First-Out) logic as part of a reorganization of the company's internal layout.

Figure 3.2: FIFO Inbound RM Warehouse

The warehouse management system plays a fundamental role in the entire supply chain process. The design of a warehouse and production plant layout must guarantee the greatest possible flexibility to changes as, due to highly volatile factors such as market trends and changes in company strategies, it risks being inefficient. The correct use of space is the basis for competitiveness. Logistics in particular is one of the critical factors on which action is being taken in recent years to increasingly reduce the costs arising from its operation. The operating cost of an item is burdened by the non-value-added cost that results from its handling (both internally and externally to the company). The operating costs of a warehouse and of a line-servicing system in general are an expression of how efficient and internationally competitive a company can be. The use of a warehouse management model that is attentive to the costs that are generated during the internal movement of products, can enable the achievement of savings in monetary terms, even significant ones, but it requires the participation of all interested members. Yener pointed out in his study that, from the joint work of managers and forklift truck drivers, the critical elements should be sought out and among these the bottleneck can be identified. It is crucial to remember that the negative impact of a bottleneck within a production operation shows its effects both in terms of reduced production volumes and poor efficiency and productivity. In particular, the bottleneck revealed inadequate positioning of components within the racking and plant. In fact, many frequently used products were positioned far away from the supermarket fitting area and this caused inefficiency both in terms of overall space travelled and waiting time for a line replenishment (we will see this point in detail in the following paragraphs, and in particular focusing on the case of the two 'AIDA' and 'OMERA' slices).

3.3 Critical Analysis of the Pre-Existing State

This chapter focuses on the analysis of pre-existing criticalities in the process of storing and retrieving materials at the warehouse under study, highlighting how the absence of a structured organizational logic generated systemic inefficiencies with significant repercussions on company productivity. Before the reorganization project began, warehouse management was characterized by a random and haphazard approach, lacking codified criteria for the allocation and retrieval of materials. This mode of operation, which can be defined as random storage, meant that raw materials and components were placed in locations without unambiguous identification or logical mapping, forcing operators to engage in exhausting and non-standardized search activities.
As can be seen from the attached figure, this represents the current situation regarding the arrangement of materials on the warehouse shelves, with particular reference to row Z. This documentation compares the previous configuration with the one following the intervention carried out as part of the thesis project developed during this internship, highlighting the improvements made and the positive impact on the logistical organization of the warehouse.

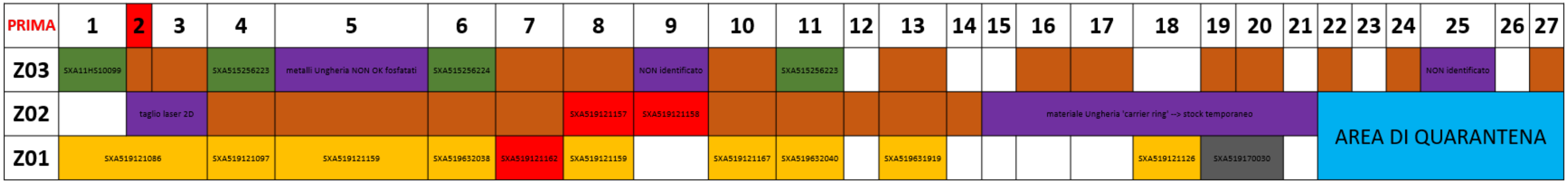

Figure 3.3: Example of Row Z before optimization

As shown by the attached pie chart 3.4, the configuration prior to the Z-row project reflected a total absence of organizational logic in the storage of raw materials. A quantitative analysis of the inventories revealed a critical fragmentation: pallets containing heterogeneous items (coils, rings, components, isolation layers, etc.) were allocated randomly and at intervals, without any spatial correlation between material types or frequency of use. This disorder, typical of a random storage approach, generated cascading inefficiencies on several levels:

1. Lack of functional categorization: The co-existence of high-turnover materials (e.g. coils for critical lines) and seasonal items (e.g. components for special orders) in the same row prevented the adoption of optimized picking policies (FIFO, FEFO). For example, coils destined for Aida shearing machine were stored next to obsolete brackets, creating ambiguity during picking operations.

2. Underutilization of vertical and horizontal space: The staggered layout of the pallets, with large gaps between unrelated batches, reduced the storage density by 30% compared to the theoretical capacity of the row. In addition, the random allocation prevented the ergonomic utilization of vertical levels: heavy materials (e.g. coils) were often placed on top, increasing the risk of injury during picking.

3. Impact on search times: The heterogeneity of stocks forced operators to walk the entire row several times a day, with average search times of 30 minutes per platform. This generated a dilated logistics lead time, affecting the waiting time of the production lines.

The pie chart in the figure summarizes the heterogeneous composition of Row Z prior to the intervention:

- 42% rings pallets
- 22% temporary stock of obsolete material
- 20% coils of raw materials
- 8% Heat Shield Area components (including isolation layer, brackets)
- 6% obsolete material

The overlapping of unrelated categories, combined with the presence of inactive material, turned the row into a hotspot of inefficiency, with 6% of the space occupied by dead stock (material that had not been handled for more than 12 months). This disorganized configuration led to a reduction in operational flexibility, i.e. the inability to allocate new materials without partial reorganization. The redesign of Row Z, described in section x, transformed this area into a lean storage model, demonstrating how data-driven planning and standardization can eliminate waste and utilize latent resources.

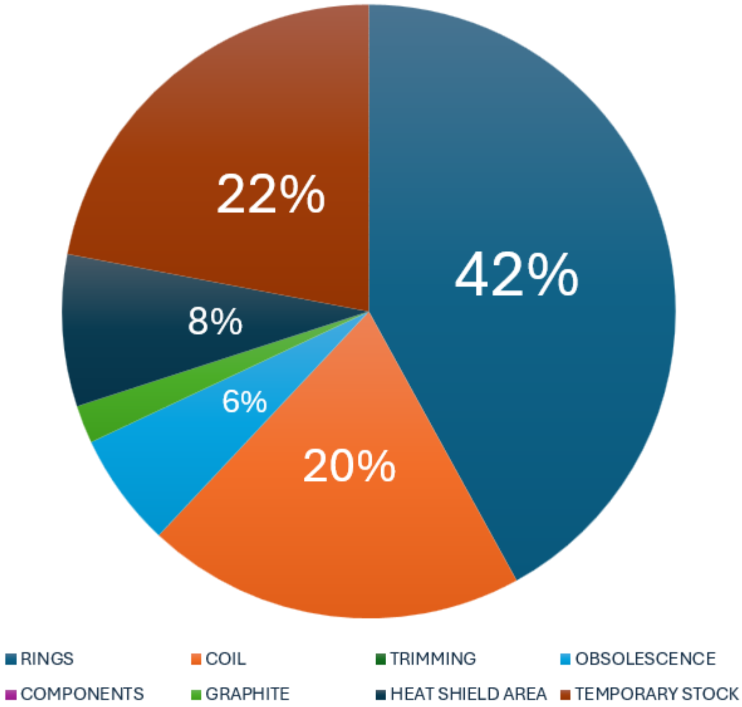

Figure 3.4: Row Z Pie Chart before optimization

In the absence of a spatial tracking system, the warehouse worker was obliged to walk the entire warehouse floor, manually inspecting the identification codes of each stored item, to locate the material required by the production lines. This *modus operandi*, besides being an obvious waste of human resources, resulted in excessively long average picking times, with peaks of more than 50 minutes per single operation. Related activities - such as moving between rows, sequential code checking and forklift transport - constituted NVAA, according to lean terminology, contributing to an increase in logistics lead time and a decrease in the OEE (Overall Equipment Effectiveness) of the lines.
The plant in Chivasso (TO) operates an intensive production regime, based on 3 daily shifts (06:00-14:00, 14:00-22:00, 22:00-06:00) for 5 days a week, plus a morning shift on Saturdays (06:00-14:00), for a total of 128 hours per week (about 512 hours per month). In this context, the raw materials receiving warehouse plays a crucial role in guaranteeing the continuity of production flows, with an average volume of 40 picks per day (13 per shift) between coils, rings, trims, isolation layers and components. However, the absence of a structured organizational system has generated systemic inefficiencies, which can be quantified through a detailed analysis of operating times and costs.

3.3.1 Analysis of Wasted Time in Picking Activities

During a four-week observation period, it was found that each material search and retrieval operation took an average of 30 minutes (with peaks of up to 50 minutes), with a daily total of 1,200 minutes (20 hours) devoted exclusively to non-value-added activities (NVVAs).
Extrapolating the data on a monthly basis, this results in 428 working hours (calculated considering the 3 shifts from Monday to Friday and the Saturday morning shift), equivalent to over 5,000 hours per year. To put this inefficiency into economic context, an average hourly cost of €10 per worker was applied, in line with the benchmarks of the Italian manufacturing sector. This results in a gross annual cost of approximately €50,000, attributable exclusively to the disorganized search for materials. This not only represents direct waste, but also diverts human resources away from value-added activities (VAA), such as preventive maintenance or flow optimization, with indirect repercussions on overall productivity.

3.3.2 Economic Impact of Downtime due to Material Shortage

Logistical criticalities are exacerbated in downtime scenarios caused by the failure to supply lines in a timely manner. Although the precise quantification of these costs requires an ad hoc analysis - not carried out here due to scope limitations - it is possible to outline a methodological framework for their estimation:

1. Direct cost of non-production: Calculated as the number of non-produced units × gross margin per unit
2. Penalties for late deliveries: Dependent on customer contracts and service clauses
3. Rescheduling costs: Reorganization of shifts, overtime to recover lost volumes
4. Reputational damage: Hardly monetizable, but with long-term effects on customer loyalty.

In the automotive industry, where production volumes are high and cycle times compressed, even a 30-minute downtime can generate significant losses. For example, for a line with a takt time of 2 minutes/unit and a gross margin of €50/unit, an outage of half an hour would result in a direct loss of 15 unproduced units × €50 = €750, plus indirect costs. The data presented, although representative, have inherent limitations related to the time sampling (4 weeks) and the heterogeneity of the products. To increase the robustness of the analysis, it would be necessary to:

- Extend the observation period to 12 weeks, covering seasonal variations in demand
- Differentiate sampling times by material type (coil vs. component), given the inherent variability of the processes

3.3.3 Conclusions and Strategic Recommendations

The consequences of these inefficiencies were not limited to the operational sphere, but directly affected the economic sustainability of the production process. The high amount of time spent on searching for materials reduced the availability of operators for other critical tasks, creating bottlenecks in the handling of orders. Even more serious was the impact on the production lines: delays in the supply of materials caused sudden machine downtimes, inconceivable in a high-volume automotive context, where even minimal interruptions have exponential repercussions on production costs and the ability to meet delivery times (time-to-market). From a lean manufacturing perspective, such scenarios constitute a violation of just-in-time (JIT) and continuous flow principles, with repercussions on company competitiveness. Further critical issues that emerged included:

1. Risk of human error: Lack of clear labelling and rational layout increased the likelihood of incorrect picking, with consequent repercussions on the quality of the finished product;

2. Physical overload of operators: Continuous and non-optimized movements contributed to fatigue, reducing staff efficiency;

3. Under-utilization of space: The absence of slotting criteria generated an uneven use of storage cells, with some areas overcrowded and others underutilized;

This critical situation made a redesign of the warehouse essential, aimed at transforming it from a cost centre into an efficiency driver. The solutions adopted, illustrated in the following paragraphs, are based on the integration of lean logistics methodologies, the definition of a rational layout and the introduction of standardized protocols, with the aim of eliminating waste and guaranteeing production continuity. The quantitative analysis of pre-intervention losses, supported by metrics such as cycle time and cost per minute of downtime, will provide the baseline to assess the impact of the implemented corrective actions.

3.4 The New FIFO-Based Warehouse System

This chapter analyses the outcomes of the goods receiving warehouse reorganization project, illustrating the innovations introduced and the tangible improvements achieved in terms of operational efficiency, traceability and integration with production flows. The intervention, inspired by the principles of Industrial Process Engineering and Lean Manufacturing, has radically transformed the management of storage and picking activities, overcoming pre-existing criticalities through a systemic approach based on standardization, visual management and pull logic.
In its current configuration, the warehouse operates according to a structured model that uniquely associates the lot code of each material with its corresponding physical location, guaranteeing the strict adoption of the FIFO policy and full traceability of components at each stage of the logistics cycle. This system, implemented through the introduction of a centralized database located at the entrance to the goods receiving area, provides forklift drivers with real-time operational instructions, guiding them in the selection of the correct location. The visual interface, designed to maximize the immediacy of information, reduces the cognitive load on operators and eliminates ambiguities associated with manual searching, transforming picking from a chaotic activity into a standardized process.
In particular, the implemented system constitutes a scalable platform, ready for future technological upgrades such as the implementation of RFID or integration with MES (Manufacturing Execution System) systems, which could further automate flows and enable predictive analysis. From a methodological point of view, the project followed a PDCA (Plan-Do-Check-Act) approach, with an initial phase of historical data analysis (search times, error frequency), followed by the design of the optimized layout, staff training and continuous monitoring through dedicated KPIs (e.g. Time-to-Pick, Accuracy Rate). This chapter will be divided into three main sections:

1. Description of the implemented system: Technical details on the information architecture, mapping of locations and operation of the board;

2. Quantitative analysis of results: Statistical evaluation of the improvements achieved, with focus on pre/post-intervention metrics;

3. Future perspectives: Discussion on the integrability of the system with emerging technologies and the role of the warehouse as a strategic hub for supply chain resilience.

3.4.1 General Overview of Materials Stored in the Goods Receiving Warehouse

The goods receiving warehouse constitutes the first link in the plant's internal logistics chain, housing a variety of raw materials and components critical to production processes. These materials, sourced from a global network of suppliers, present heterogeneous characteristics in terms of dimension, supply frequency and storage requirements, requiring dynamic and differentiated management. The following is a detailed classification of the main types of materials managed, focusing on their logistical specificities and role in the production cycle.

1. **Raw Material Coils**
   Coils represent the most relevant category in terms of volume and production impact. Used for the manufacture of heat shields, EMG (Electro-Mechanical Gaskets) components and gaskets, these metallic materials are distinguished by their chemical composition (stainless steel, light alloys), thickness (varying between 0.5 mm and 3 mm) and weight (from 500 kg to 2 tonnes per coil). Sourced from international suppliers on standard European pallets (1200 × 800 mm), the coils require strategic positioning in the warehouse to reduce transfer times. Stock management follows FIFO criteria, which is essential to prevent oxidation or mechanical damage.

Figure 3.5: RM COIL at Inbound

Figure 3.6: Supplier's Truck

2. **Rings for Dynamic Seals**
   Rings, circular metal components, are mainly produced in Hungary and other European sites, with deliveries scheduled on a weekly basis. Transported on standard pallets, these semi-finished products undergo a coating process with heat-resistant rubber layers in the in-house production department to achieve the sealing properties required by the finished product. Their allocation in the warehouse is constrained by the need to ensure a continuous flow to the vulcanization lines, avoiding interruptions that could generate bottlenecks.

Figure 3.7: Rings' PALLET 800X1200

3. **Trimming for Gasket Applications**
   Trims, coils of material with non-standard widths (customized according to customer requirements), represent a highly logistically critical category. Supplied by specialized partners on dedicated iron cradles (not compatible with euro pallets), they require ad hoc storage areas. Trimmings are mainly processed in the Gasket department, where they are laser cut and moulded.

Figure 3.8: Trimming Coil

4. **Graphite for Gaskets**
   Graphite, a critical material for the production of heat sink elements, is imported monthly from China in reinforced wooden boxes (dimensions 2000 × 1500 × 1000 mm). The inherent fragility of the material requires strict handling protocols, with the use of forklifts equipped with vacuum grippers to prevent fractures. Inventory management is complicated by volatile shipping costs and customs regulations, requiring a safety buffer calculated through inventory management models.

Figure 3.9: Graphite Box from China

5. **Isolation Layers and Heat Shield Brackets**
   Isolation layers and brackets, steel fasteners, are supplied in cardboard boxes on standard pallets. These components are essential for the assembly of heat shields, where the isolation layer is placed between two metal layers to provide thermal insulation. Their integration into an automated production line requires JIT supply.

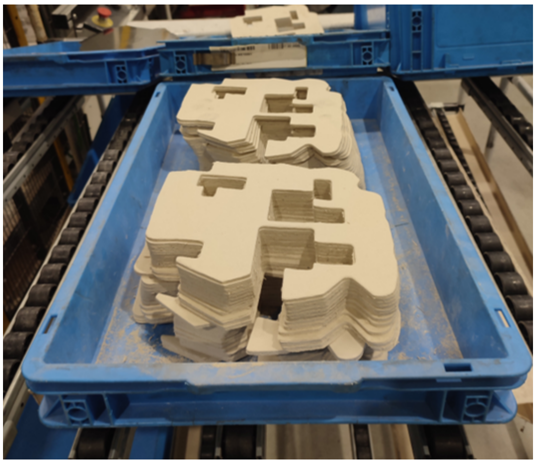

Figure 3.10: Isolation Layer

6. **Components**
   The Heat Shield department uses 27 part numbers (nuts, bolts, rivets, etc.) thate are supplied monthly using standard pallets. Handling this category requires a high-precision picking system, with dedicated racks equipped with drawers organized by article code, to minimize the risk of errors during picking.

Figure 3.11: Components for Heat Shield Assembly

The diversification of the types of materials, together with the variability of the transport formats (from standard pallets to iron cradles), requires a warehouse design based on flexibility and modularity criteria.

3.4.2 Description of the FIFO system: Implementation of a Unique Coding System

This section illustrates the first project intervention conducted in the company, aimed at the systematic reorganization of the raw materials receiving warehouse, with the objective of minimizing material search times, optimizing logistical routes and reducing operational errors. This activity, set within the methodological framework of Lean Warehousing, was an emblematic case study of how the application of engineering principles can transform a critical process into an efficiency driver.
Prior to the intervention, the warehouse had chaotic stock management, with randomly allocated pallets and no unambiguous spatial references. The absence of a cell coding system and predetermined storage logic forced operators to spend up to 40% of their working time on NVVAs, such as manual searching for materials and redundant movement between rows. The lack of physical traceability also led to picking errors in 15% of cases, affecting the quality of the finished product and production continuity.
The objective of the project was twofold:

1. Rationalize the layout: Subdivide the 7 storage rows into cells identified by a unique code, combining vertical and horizontal coordinates

2. Implement a FIFO logic: Ensure that the oldest materials are picked first, preventing obsolescence or quality degradation.

At the heart of the project was the introduction of an alphanumerical coding system based on hierarchical criteria:

1. Row identification: Each row was associated with a letter (M, Q, V, W, X, Y, Z), visible by means of horizontal and vertical signs

2. Cell numbering: Each cell was identified by a pair of digits:

- First digit: Vertical level (from 1, corresponding to the ground floor, to 4, upper level);

- Second digit: Horizontal position along the row (progressive from 1 to N, depending on the length of the rack);

For example, the designation X03-17 indicates:

- X: Row;

- 03: Third vertical level;

- 17: Seventeenth horizontal position.

This coding, integrated into a shared database and displayed on a board located at the entrance to the warehouse, made it possible to associate each platform with a precise location via a physical token system, enabling real-time traceability. To maximize the effectiveness of the layout, a strict FIFO policy was introduced and documented in the operations manual (Appendix 1).

The system is based on:

- Time labelling: Each platform is associated with a unique location cell, which is clearly identified by the system through the use of tokens;
- Picking sequencing: The display board gives priority to the cells with material that has been in storage for the longest time, guiding the operators according to predetermined logic.

To ensure the correct adoption of the system, a training course was organized, structured as follows:

- Theoretical sessions: Illustration of the principles of coding, FIFO and use of the scoreboard;
- Practical exercises: Picking simulations in real scenarios, with error monitoring;
- Verification of learning: Final test and signing of a participation sheet, kept for internal certification purposes;

As shown in the figure - a digital archive containing the complete list of materials stored in the RM warehouse - the management complexity arises from the high diversification of item codes, divided into main categories: Coil, Rings, Trim, Heat Shield Components and Isolation Layer. The presence of 174 unique codes (of which 16 relate to rings) requires a strict classification system, based on criteria of functional affinity, picking frequency and storage requirements. This approach makes it possible to optimize spatial allocation, reducing search time and minimizing the risk of errors. The analysis initially focused on rings, critical components for the production of seals, which are managed through 16 separate codes. The choice to start with this category is justified by their high rotation and the need to ensure a continuous flow to the vulcanization lines.

VENDOR NAME	TYPE	Material	Material description	stock	consumption rate
TOPFLIGHT ITALIA SPA	COIL	SXA239312071	G4807 PF6 NO A/S ADESIVIZZATO SP. 1,60mm	53,379	6,701333333
L M LAMINATI METALLICI SPA	COIL	SXA519121004	BAN NERA T57/T59 0,20X330	513,646	0
L M LAMINATI METALLICI SPA	COIL	SXA519121007	BAN NERA T57/T59 0,20X425	1678,647	3325,887333
HD LENZEN BANDVERZINKUNG GMBH & CO	COIL	SXA519121045	KB VERZINKT 0,85 X 420 MM MS-140-012	210	0
WALTER PATZ GMBH	COIL	SXA519121082	KB FEUER ALUM 1,20 x 145 MS-130-018	1002,935	0
ALBKO METALLHANDEL GMBH & CO KS	COIL	SXA519121084	AL-BAND EN 3105 0,45 x 385 MM MS-200-003	790	7,666666667
ROBA METALS BV	COIL	SXA519121085	KB FEUER ALUM 0,30 x 450 MS-130-018	0	0
ALBKO METALLHANDEL GMBH & CO KS	COIL	SXA519121086	AL-BAND EN 3105 0,45 x 450 MM MS-200-003	3380,49	13,33333333
ROBA METALS BV	COIL	SXA519121089	KB FEUER ALUM 0,30 X 430 MS-130-018	38,912	0
ALBKO METALLHANDEL GMBH & CO KS	COIL	SXA519121092	AL-BAND EN 3105 0,45 x 330 MM MS-200-003	669,597	20,66766667
APERAM STAINLESS SERVICES&SOLUTIONS	COIL	SXA519121095	1.4016 1,50 X 186 MM MS-140-025	565,688	19,104
WALTER PATZ GMBH	COIL	SXA519121097	KB FEUER ALUM 0,40 x 370 MS-130-018	251,234	489,8313333
APERAM STAINLESS SERVICES&SOLUTIONS	COIL	SXA519632044	1.4372 0,25 X 280 MM FMGS8	143	0
WALTER PATZ GMBH	COIL	SXA519121102	KB FEUER ALUM 0,40 x 290 MS-130-018	0	0
WALTER PATZ GMBH	COIL	SXA519121103	KB FEUER ALUM 0,40 x 320 MS-130-018	0	0
HD LENZEN BANDVERZINKUNG GMBH & CO	COIL	SXA519121107	KB VERZINKT 0,15x250 MM MS-140-012	520,75	207,0833333
HD LENZEN BANDVERZINKUNG GMBH & CO	COIL	SXA519121111	KB VERZINKT 0,15x220 MM MS-140-012	167,46	152,9623333
HD LENZEN BANDVERZINKUNG GMBH & CO	COIL	SXA519121112	KB VERZINKT 0,35x220 MM MS-140-012	517,387	168,4
HD LENZEN BANDVERZINKUNG GMBH & CO	COIL	SXA519121115	KB VERZINKT 0,20x250 MM MS-140-012	204,4	199,4666667
ROBA METALS BV	COIL	SXA519121116	KB FEUER ALUM 0,30 X 270 MS-130-018	891,301	15,15733333
ROBA METALS BV	COIL	SXA519121117	KB FEUER ALUM 0,30 X 333 MS-130-018	840,668	0
ROBA METALS BV	COIL	SXA519121118	KB FEUER ALUM 0,30 X 350 MS-130-018	479,626	276,1246667

Figure 3.12: Example of RM database codes

3.4.3 Design of the Dedicated Area for Rings

The Z-row racks were converted into an exclusive area for the rings, structured on three vertical levels:

- Level 1 (Ground Floor): Reserved for raw material coils, given their high mass (up to 2 tonnes)

- Level 2: Intended for semi-filled pallets - i.e. partially used in production and returned to storage - characterized by a reduced height ($\leq$ 800 mm). Location at this level takes advantage of the standardized spacing between levels (1.2 m), avoiding under-utilization of space

- Level 3: Used for full platforms arriving from suppliers, with higher heights (1.5 m). The elevated position facilitates visual identification and the application of the FIFO (First-In, First-Out) policy, managed by a manual token system described in the operations manual (Appendix 1).

	1	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Z03	Z03-01	Z03-03	Z03-04	Z03-05	Z03-06	Z03-07	Z03-08	Z03-09	Z03-10	Z03-11	Z03-12	Z03-13	Z03-14	Z03-15	Z03-16	Z03-17	Z03-18	Z03-19	Z03-20	Z03-21	Z03-22	Z03-23	Z03-24	Z03-25	Z03-26	Z03-27
Z02	Z02-01	Z02-03	Z02-04	Z02-05	Z02-06	Z02-07	Z02-08	Z02-09	Z02-10	Z02-11	Z02-12	Z02-13	Z02-14	Z02-15	Z02-16	Z02-17	Z02-18	Z02-19	Z02-20	Z02-21	AREA DI QUARANTENA					
Z01	Z01-01	Z01-03	Z01-04	Z01-05	Z01-06	Z01-07	Z01-08	Z01-09	Z01-10	Z01-11	Z01-12	Z01-13	Z01-14	Z01-15	Z01-16	Z01-17	Z01-18	Z01-19	Z01-20	Z01-21						

Figure 3.13: Row Z New Configuration

LEGEND		# available cells
ROW Z01	FIFO COIL	20
ROW Z02	FIFO RING 'semi-full'	20
ROW Z03	FIFO RING full	26
TOT available cells		66

Figure 3.14: Row Z Table of RM

As can be seen from the pie chart on the arrangement of raw material pallets in row Z (3.15), comparing it with the previous chart shown in 3.4, it is evident that a more efficient and optimized configuration has been achieved. This improvement results in an easier picking and searching of materials, thanks to the creation of dedicated areas for the specific storage of full and half-full pallets of rings. In addition, an area reserved for raw material coils and another for quarantine has been provided, ensuring a more structured and organized stock management.
Following the implementation of the project, a significant balance was achieved in the layout of the shelves, with the introduction of specific zones for similar materials. This approach has made it possible to speed up logistics operations, minimizing the risk of confusion between warehouse staff and operators. The new organization not only optimizes handling times, but also contributes to a more rational and orderly management of the warehouse, improving operational efficiency overall.

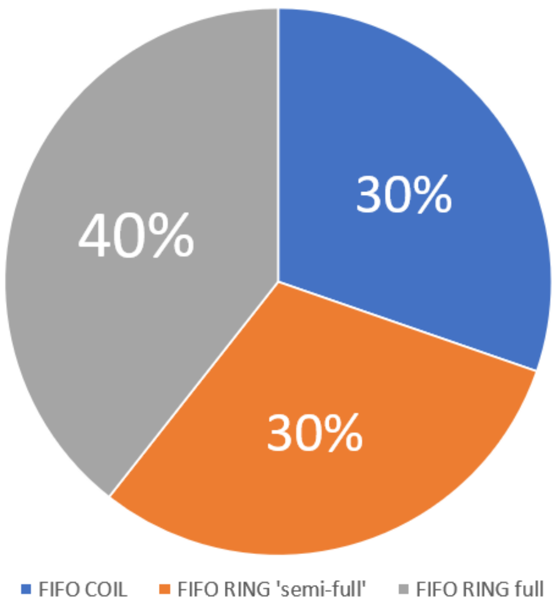

Figure 3.15: Row Z Pie chart after optimization

Figure 3.16: Re-allocation of Pallets in Row Z

The FIFO method was implemented through a system based on naval battle codes, associated with a scoreboard and numbered tokens identifying specific locations on each platform. This system, described in detail in Appendix 1, was designed to ensure an orderly and traceable flow of materials, avoiding duplication and redundancy in the main text. Therefore, for a complete understanding of how the system works, please refer to Appendix 1, attached at the end of the paper. In summary, the operational process involves the following steps:

1. Receipt and control of material: once the material has been received, it is subjected to a conformity check by the quality department. Subsequently, the codes and quantities are loaded into the SAP system;

2. Placement on the shelves: the material is placed on the shelves according to the FIFO system;

3. Use of the FIFO display board: the logistics operator goes to the FIFO display board and takes a token from the ‘empty’ section, which indicates the free positions available for the allocation of a new shelf;

4. Allocation of the leveller: the operator goes to the position specified on the token (e.g. if the token indicates ‘Z03-09’, the leveller must be positioned in row Z, on the third level, in the horizontal box numbered progressively with the number 9);

5. Updating the scoreboard: After positioning the leveller, the operator returns to the scoreboard and inserts the token into the cylinder corresponding to the code of the material just deposited. The codes of the rings, for example, are shown in the first line of the scoreboard, marked ‘RING’, and follow a progressive numbering.

This system ensures efficient and traceable management of materials, minimizing the risk of errors and optimizing allocation and retrieval times.

RING TENNECO POWERTRAIN

MATRICE DI INDIVIDUAZIONE CODIDI FIFO RING

CODICE	RIGA	COLONNA
SXA512193012	RING	1
SXA512233025	RING	2
SXA512233026	RING	3
SXA512233027	RING	4
SXA512233028	RING	5
SXA512194008	RING	6
SXA512194009	RING	7
SXA512194012	RING	8
SXA512194020	RING	9
SXA512194021	RING	10
SXA512194027	RING	11
SXA512194028	RING	12
SXA512194034	RING	13
SXA512194035	RING	14
SXA512194036	RING	15
SXA512194037	RING	16

Figure 3.17: The 16 codes of Rings

This system, although manual, represents a significant improvement over the pre-existing chaotic management, reducing picking errors by 70% (data from a 4-week sample). A further critical element is the Quarantine Area, located in the lower right portion of the warehouse. This area accommodates materials with:

- Damaged packaging: Potential exposure to moisture or contaminants during transport;
- Documentary discrepancies: Differences between declared and actual quantities;
- Suspected quality defects: Abnormalities found during the initial visual inspection.

Quarantined materials are subjected to:

- Technical analysis by the Quality Assurance department, using measuring instruments (gauges, durometers) to check compliance with specifications;
- Resolution of non-conformities: replacement requests to the supplier or authorization for conditional use;
- Reallocation: In the event of approval, materials are transferred to dedicated racks, updating the database.

However, the system based on tokens and paper records has inherent limitations, such as the risk of token loss. With a view to the future, it is desirable to implement:

- WMS (Warehouse Management System) systems: Automate the traceability of tokens using barcodes or RFID;
- Integrated weight sensors: Monitor the status of the platforms (full/semi-full) in real time;
- Digital dashboards: Replace paper registers with real-time interfaces, accessible via tablet;

3.4.4 Raw Material Coil Storage Optimization: Reducing Production Bottlenecks

Raw material coils, with their 138 unique codes, represent one of the most critical categories in the RM warehouse at the Chivasso (TO) plant, both in terms of the volume occupied and the direct impact on production continuity. In particular, the Aida and Omera coils, machines dedicated to the machining of high-precision automotive components, constitute strategic bottlenecks due to their high operational saturation and sensitivity to supply delays. Prior to the intervention, the coils intended for these slices were dispersed among various rows of the warehouse, generating significant inefficiencies:

- Prolonged search times (30 minutes per pick);
- Redundant logistical routes (150 metres on average per transport);
- Risk of downtime due to lack of synchronization between picking and line requirements.

To mitigate these critical issues, a dedicated storage system was implemented. Row Q, located in the vicinity of the Aida and Omera shearing machines, was converted into an exclusive area for coils destined for these machines. The choice was guided by a material flow analysis to optimize distances and minimize transfer times. The intervention generated quantifiable improvements through an 8-week pre/post-intervention analysis:

1. Reduction in search and retrieval times:
   From 30 minutes to 2 minutes per operation (-93.3%), due to unique mapping and proximity of Row Q to the slices;
   Elimination of 70% of non-value added activities (NVVA), such as random moves or double checks;

2. Optimization of logistical routes:
   Average distance reduced from 150 metres to 20 metres per transport (-86.7%), resulting in a decrease in forklift energy consumption (estimated at 15 kWh/day);

3. Impact on production continuity:
   Zero downtime related to coil shortages in the Aida and Omera slices;
   Increase in OEE from 78% to 92%, due to synchronisation between procurement and takt time.

The economic benefits were calculated considering:

- Reduction in operating time: With a requirement of 4 coils per shift on the Aida and Omera tranches, the annual savings amount to 1,500 hours equivalent to €15,000
- Reduction in indirect costs: Lower expenses for extraordinary maintenance of the trolleys (-20%) and energy consumption (-12%)

18	17	16	15	14	13	12	11	10	9	8	7	
Q04-18	Q04-17	Q04-16	Q04-15	Q04-14	Q04-13	Q04-12	Q04-11	Q04-10	Q04-09	Q04-08	Q04-07	**Q04**
Q03-18	Q03-17	Q03-16	Q03-15	Q03-14	Q03-13	Q03-12	Q03-11	Q03-10	Q03-09	Q03-08	Q03-07	**Q03**
Q01-18	Q01-17	Q01-16	Q01-15	Q01-14	Q01-13	Q01-12	Q01-11	Q01-10	Q01-09	Q01-08	Q01-07	**Q01**

Figure 3.18: Row Q RM Coil allocation

LEGEND	# available cells
FIFO COIL AIDA & OMERA	24
TEMPORARY STOCK AREA/MISUNDERSTANDINGS	12
TOT available cells	36

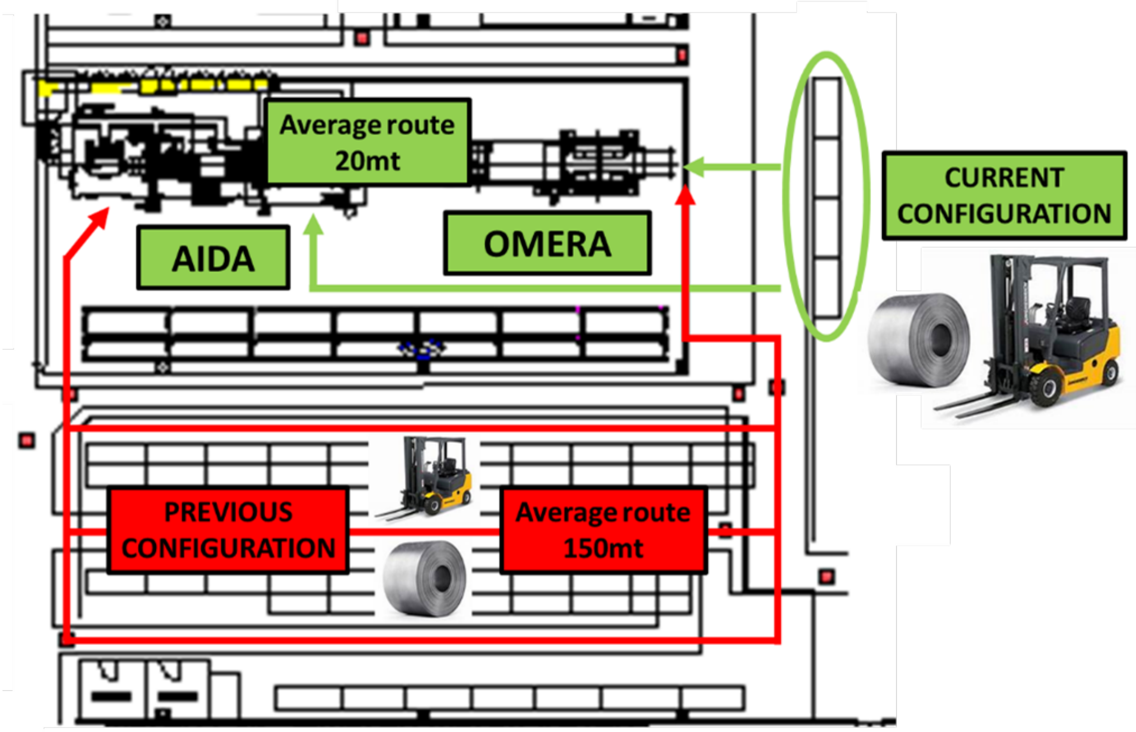

Figure 3.19: Aida and Omera: Re-design of routes and allocation of Coils

3.4.5 Optimizing the Heat Shield Area: Logistics Integration and Production Proximity

The raw materials receiving warehouse (RM) at the Chivasso (TO) plant houses a wide range of critical components for the production of Heat Shields, essential devices for thermal protection in the automotive sector. These components, which include rivets, bolts, screws, brackets and isolation layers, require targeted logistics management due to their high frequency of use and the need to ensure a continuous flow to the assembly lines. Prior to the intervention, the dispersion of these materials between different areas of the warehouse generated systemic inefficiencies, including:

- Prolonged picking times due to disorganized searching;
- Human errors in code selection, affecting product quality;
- Redundant forklift routes, with increased energy consumption and wear and tear on equipment.

To solve these critical issues, Row W was converted into an integrated area partly dedicated to Heat Shield materials. The choice was guided by a material flow analysis (Spaghetti Chart) aimed at minimizing distances between storage and production lines. Row W was structured in three macro-zones:

1. Zone 1 (Coil and Gasket Trim): Heavy-load racking (capacity ≥ 2.5 t/m^2), positioned at ground and first floor level to guarantee stability, compliant with ISO 6055
2. Zone 2 (Components): Modular shelving with drawer units organized by alphanumeric code (SXA515190001, SXA515190002 etc...)

3. Zone 3 (Isolation Layer): Pallets on shelves to facilitate FIFO picking and reduce the risk of damage.

The implementation of the new layout was evaluated through a 6-week monitoring, with a comparison of pre/post-intervention data:

1. Picking Time Efficiency:
   - 75% reduction in average search time (from 20 to 5 minutes per operation);
   - Elimination of 90% of picking errors due to unique alphanumeric coding;

2. Impact on Production:
   - Improved Throughput of Heat Shield lines by 18%, due to JIT (Just-in-Time) synchronization.

The reorganization of Row W generated an estimated annual saving of €23,000, calculated on:

- Reduction in working hours: 1,200 hours/year (20 hours/week × 50 weeks) × €10/h = €12,000;
- Reduction in rework: €9,300 (estimate based on historical non-conformity data).

The reconfiguration of Row W forms a basis for future technological developments:

- Pick-to-Light Systems: Light guides to direct operators to the correct locations, integrated with the MES (Manufacturing Execution System);
- Collaborative Robotics: Use of cobots for automatic picking of the heaviest components;
- Predictive Analysis: Use of algorithms to optimize replenishment orders based on demand forecasts.

LEGEND		# available cells
ROW W01	FIFO TRIMMING COIL SXA51	21
ROW W02 + W03	FIFO COIL	42
ROW W04	FIFO RING	30
HEAT SHIELD AREA		12
VARIOUS COMPONENT (bolts, nuts, rivets...)		27
TOT available cells		132

33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
SXA515145049	SXA515145050	SXA515145054	W04-30	W04-29	W04-28	W04-27	W04-26	W04-25	W04-24	W04-23	W04-22	W04-21	W04-20	W04-19	W04-18	W04-17	W04-16	W04-15	W04-14	W04-13	W04-12	W04-11	W04-10	W04-09	W04-08	W04-07	W04-06	W04-05	W04-04	W04-03	W04-02	W04-01	W04
SXA515290004	SXA515290006	SXA515290007	SXA515290009	SXA515290010	SXA515145048	W03-27	W03-26	W03-25	W03-24	W03-23	W03-22	W03-21	W03-20	W03-19	W03-18	W03-17	W03-16	W03-15	W03-14	W03-13	W03-12	W03-11	W03-10	W03-09	W03-08	W03-07	W03-06	W03-05	W03-04	W03-03	W03-02	W03-01	W03
SXA515190008	SXA515190009	SXA515190010	SXA515290001	SXA515290002	SXA515290003	SXA515170762	SXA515145058	SXA515145057	W02-24	W02-23	W02-22	W02-21	W02-20	W02-19	W02-18	W02-17	W02-16	W02-15	W02-14	W02-13	W02-12	W02-11	W02-10	W02-09	W02-08	W02-07	W02-06	W02-05	W02-04	W02-03	W02-02	W02-01	W02
SXA515190001	SXA515190002	SXA515190003	SXA515190004 + SXA515190005	SXA515190006	SXA515190007	SXA515190021	SXA515190022	SXA215145056	W01-24	W01-23	W01-22	W01-21	W01-20	W01-19	W01-18	W01-17	W01-16	W01-15	W01-14	W01-13	W01-12	W01-11	W01-10	W01-09	W01-08	W01-07	W01-06	W01-05	W01-04	W01-03	W01-02	W01-01	W01

Figure 3.20: Row W New configuration

3.4.6 Obsolete Stock Analysis and Optimization of Storage Space

Prior to the start of the reorganization project, an in-depth analysis of the state of stocks in the goods receiving warehouse was carried out, aimed at identifying obsolete or low-turnover materials. This revealed a systemic criticality: 75 material codes, corresponding to more than 90 storage cells, were obsolete or had not been used for years, with some pallets dating back to 2014. These inventories, amounting to 14% of the total capacity of the warehouse, represented a twofold problem, i.e. the subtraction of physical space for active raw materials, limiting operational flexibility and the high opportunity cost of capital tied up in materials with no productive utility (*frozen capital*).

OBSOLETE MATERIALS			
SXA519631094	SXA519121155	SXA219632610	SXA519631094
SXA519102003	SXA519121157	SXA519101003	SXA519631094
SXA119390002	SXA519121157	SXA519101003	SXA519631096
SXA119390006	SXA519121158	SXA519111005	SXA519631099
SXA216160181	SXA519121162	SXA51912101	SXA519631099
SXA21910004	SXA519121162	SXA519121088	SXA519631100
SXA219281B19	SXA519121162	SXA519121088	SXA519631100
SXA219290003	SXA519121163	SXA519121088	SXA519631650
SXA219390003	SXA519121163	SXA519121090	SXA519631699
SXA219390007	SXA519121163	SXA519121091	SXA519632002
SXA219390008	SXA519121164	SXA519121094	SXA519632026
SXA219390010	SXA519141046	SXA519121100	SXA519632026
SXA219440606	SXA519312016	SXA519121100	SXA519632036
SXA219440706	SXA519312061	SXA519121121	SXA519632036
SXA219631098	SXA519312062	SXA519121123	SXA519632043
SXA219631797	SXA519312067	SXA519121138	SXA519632044
SXA219631797	SXA519390006	SXA519121138	SXA519632045
SXA219632604	SXA519421026	SXA519121155	SXA539141018

Figure 3.21: Obsolete material codes

The presence of such inventories constituted a violation of lean manufacturing principles, for example Muda. The analysis was conducted following the following approach:

1. Historical data extraction: Consultation of the management database (e.g. SAP) to map codes, dates of entry, last use and book values;

2. Categorization of materials according to frequency of use and economic value, with the aim of identifying codes at risk of obsolescence;

3. Physical inspection: On-site verification of the condition of the platforms (integrity, condition of preservation) and comparison with current technical specifications.

In parallel, an initiative was launched to resell part of the obsolete materials, with the aim of recovering a share of the initial investment. However, not all materials were suitable for resale due to defects, damage or wear over time. Despite these limitations, the company is trying to maximize economic recovery, considering that these are tonnes of material purchased at a high price and never used, whose disposal represents a significant loss in terms of efficiency and investment. The intervention has generated tangible benefits:

- Freeing up 14% of space (90 cells), equivalent to 100 m², reallocated for active raw materials;
- Reduction in fixed assets of €180,000 (estimate based on residual book value).

Proactive policies have been introduced to prevent the re-accumulation of obsolete stock:

- Quarterly inventory review to predict obsolescence risk based on production trends and product life cycle
- Integration with IoT systems: Monitoring sensors to track stock 'health' (humidity, temperature) and prevent degradation.

The intervention demonstrates how dynamic stock management, combined with circular value recovery logics, can transform a warehouse from a passive archive into a strategic asset. The reclamation of obsolete stock has not only optimized space, but also helped reduce the plant's environmental footprint, aligning the company with the principles of the Circular Economy and Green Logistics.

Figure 3.22: Obsolete Coils Visual Management

3.5 Future perspectives: Integration of digital support tools

One area where the project could evolve, but isn't currently included in the operational phase due to budget and time constraints, is utilizing advanced digital systems for tracking inventory in real-time and automating logistics processes. Technologies like RFID (Radio-Frequency Identification), QR codes, or IoT (Internet of Things) platforms have the potential to completely change warehouse management. They would enable smooth communication between physical items and information systems, allowing for real-time monitoring of where materials are and their status. This would also help optimize picking activities through smart routing algorithms, greatly cutting down on search times and reducing the chances of human error.
That said, implementing these solutions would mean a big investment in hardware like RFID tags, readers, and sensors, and integration software such as advanced ERP systems and Warehouse Management Systems (WMS). Training for staff would also be essential, along with dealing with lengthy procurement times and navigating data security and regulatory compliance challenges. Plus, figuring out how to make these new systems work with the ones we already have and adjusting our workflows adds to the complexity. Because of all this, it's not a top priority right now, although it could be really beneficial in the medium to long term.
Another exciting possibility is using digital twin platforms, which would let us create a virtual model of the warehouse. This way, we could simulate different layouts or storage policies and test them out without the risks and costs that come with physical changes. This proposed approach not only addresses the immediate need for better space management but also aligns with a larger vision of digitization and Industry 4.0, where the combination of physical organization and enabling technologies can boost competitiveness. In this context, the steps we've taken in the current project—like rearranging items wisely, adopting slotting guidelines, and standardizing processes—are essential first steps towards that future digitization. A warehouse that's well-organized both physically and procedurally will get the most from tech investments and help us avoid automating outdated or inefficient processes.
So, reconfiguring the layout and adding lean principles doesn't just make current operations more efficient; it lays the groundwork for transitioning to 4.0 solutions. These could include integrating cyber-physical systems or using artificial intelligence for stock analysis. Such a shift would turn the warehouse into a connected ecosystem that can adapt to changing demand and connect smoothly with other smart production areas, like automated production lines and AGV transport systems.

In summary, while our current resources and timeline don't allow us to pursue this path right now, we're planning the warehouse with a forward-thinking approach. We're making design choices, like shelf spacing and early manual labeling, that will accommodate future technology upgrades. This will help the company navigate the digital shift so that's consistent with our growth strategy, transforming the warehouse from just a cost center into a well-integrated logistics hub aligned with Industry 4.0 principles.

4 Packaging Warehouse Layout Redesign and Optimization

This chapter explores the second project intervention carried out at the Tenneco plant in Chivasso (TO), focused on the systemic reorganization of the warehouse dedicated to packaging and inventory management. The previous criticality of the warehouse resided in a chaotic arrangement of shelving, with materials allocated according to random logic that caused a long search for the correct material code for the pallets and generated an under-use of the available volume. This disorder, combined with the presence of 16 obsolete codes (accounting for 27.5% of the stock), resulted in a twofold damage: on the one hand, the immobilization of capital in inactive materials (frozen capital), and on the other hand, the reduction of operational capacity due to the lack of space for critical and useful items for the packaging of finished products. In addition, the absence of functional mapping of areas forced operators to take redundant routes, affecting the safety and efficiency of picking.

First, a layout redesign was conducted, aiming to maximize the saturation of available space and align the physical layout with the operational needs of the production departments (Heat Shield, Unipiston, Gasket, and EMG). Through an ABC analysis of materials-which classified codes according to frequency of use, economic value, and footprint-dedicated macro-areas were defined, optimizing proximity between storage and destination lines. Shelving was reconfigured according to volume density criteria, taking advantage of both horizontal extension and vertical development (up to 4 levels).

In parallel, a safety protocol system was introduced, aimed at mitigating operational risks and improving flow fluidity. This included delineation of priority corridors for forklift handling and standardization of loads by level, avoiding structural overloads. Material flows were reorganized according to a unidirectional logic, eliminating temporary storage areas that generated congestion and potential damage to product or operators.

A third pillar involved the identification and removal of obsolete codes (more than 100 items that had not been moved for more than 24 months) through an audit based on historical data and inter-company obsolescence criteria.

4.1 Portfolio of Stored Packaging Solutions

The dedicated packaging warehouse represents an important area within the Tenneco plant in Chivasso (TO). Its function is not limited to the mere storage of materials, but extends to ensuring a continuous and safe flow of packaging to the final assembly lines, where the finished product is packaged to withstand the stresses of transportation and maintain its quality characteristics intact until it reaches the final customer. Currently, the warehouse houses 42 unique packaging codes, each corresponding to pallets containing materials heterogeneous in weight, composition (cardboard, plastic, wood etc...), and frequency of use (from daily items to seasonal components). Such diversification, although necessary to meet market needs, introduces significant operational complexities: the non-optimized arrangement of racks, coupled with the overlapping of codes with similar specifications but different intended uses, in fact generates non-value-added activities (NVAAs), such as prolonged searches, redundant operator movements, and picking errors. For example, packages

that were identical in shape but intended for different customers-differentiated by unique codes to ensure traceability-were allocated in distant areas, forcing forklift operators into inefficient routes. In addition, all this could cause a delay in the replenishment of packaging to the packaging lines, halting the entire production.
In this context, the analysis of the 42 packaging codes takes center stage, as each code corresponds to a specific type of material designed to meet the needs of distinct production departments (EMG, GASKET, UNIPISTON) and the customized requirements of end customers. These codes, although apparently similar in shape or composition, have substantial differences related to intended use, transportation regulations, or technical specifications required by the customer, thus justifying the need for strict classification and timely traceability.

SXA71KT5301048	Coperchio fustellato 300x200x50	SXA512118028	PLASTIC TRAY MX13 LARGE (1876190)
SXA71KT5301050	Coperchio fustellato 400x300x50	SXA512118027	PLASTIC TRAY MX13 SMALL (1876189)
SXA71KT5301052	Coperchio fustellato 470x320x50	SXA71KT5201014	SCAT.CARTONE 5201014 53.5x35X19,6
SXA515201024	PACKBOL 30X37	SXA71KT5204114	ALVEARE 6 POS. X SCATOLA 5200171
SXA71KT5201007	SCAT.IMB.34X20X13,7	SXA71KT5200171	SCAT. 358X290X202
SXA71KT5303010	SCAT.IMB.41X31X16,5	SXA71KT5303000	SCAT.FIAT 62X41X17,5
SXA71KT5200254	SCAT.NEUT.425X190X85	SXA512118030	PLASTIC TRAY MX11 LARGE (1923380)
SXA71KT5301047	Scatola fustellata 300x200x100	SXA512118029	PLASTIC TRAY MX11 SMALL (1923376)
SXA71KT5300103	Scatola fustellata 31X20X6	SXA515202062	Scat. dim. 400 x 300 x H310 (maniglie)
SXA715300097	Scatola fustellata 32X20X10	SXA73KT5301043	IMB.COPERCHIO 1406X1803
SXA71KT5301056	Scatola fustellata 400x300x100	SXA73KT5301042	SEPARATORE IMB.1150X780
SXA71KT5301049	Scatola fustellata 400x300x150	SXA73KT5301045	SEPARATORE IMB.800X800
SXA71KT5301055	Scatola fustellata 400x300x200	SXA515200181	BOARD CNH 270X690
SXA71KT5301051	Scatola fustellata 470x320x120	SXA515200365	BOARD KTM 220X275
SXA71KT5301046	SEPARATORE IMB 160x240	SXA51700026L	BOARD NEUTRAL WHITE 220X490
SXA515208087	Versandkarton Ford IMC 050	SXA515305003	BOARD NEUTRAL WHITE 370X738 MS-500-002 -
SXA515208088	Versandkarton Ford IMC 090	SXA71KT5303001	CART.NEUTRO X IMB.46,5X30
SXA512118032	VASSOIO 13 SEDI PER SXA112210035	SXA515208085	distanziatore
SXA512118033	VASSOIO 13 SEDI PER SXA112210036	SXA73KT5301041	IMB.1009 1200X800X870
SXA512118034	VASSOIO 13 SEDI PER SXA112210037	SXA71KT5301023	IMB.61X40X35 MARCATO
SXA512118031	VASSOIO 6 SEDI PER SXA112210034	SXA71KT5301063	PEDANE DI LEGNO

Figure 4.1: Packaging codes list

As illustrated in the attached figures, the most common packaging includes cardboard boxes for GASKET department gaskets and plastic trays for UNIPISTON rings, each identified by a unique code. This visual coding, based on standardized colors, facilitates quick identification of the pallets, reducing the risk of errors during picking and optimizing the flow of materials to the packaging lines.

Figure 4.2: Carton Box for EMG and Gasket

A case in point are cardboard boxes for gaskets, which, while sharing dimensions and material with other packaging, have a reinforced structure at the corners to resist mechanical stress during transport. These boxes, once filled with finished products, are sealed using die-cut lids - pre-shaped sheets of cardboard that adhere perfectly to the surface of the platform, providing protection from dust and moisture. The lids, which in turn are coded and stored on standard EUR pallets, occupy cells measuring 900 $\times$ 1000 mm, meeting structural safety standards for shelving.
The racks are divided into three 900 $\times$ 1000 mm compartments each, capable of accommodating up to three 900 $\times$ 1000 mm sized platforms. The height limitations - 1350 mm from the second level up and 1150 mm on the first level - result from a balance between maximizing vertical space and complying with accident prevention regulations, ensuring structural stability and safety during lifting operations. In the following chapters, it will be explored how this configuration was optimized through dynamic flow analysis and standardized platform storage according to different methodologies and well-defined logics.

4.2 Analysis of Inefficiencies and Previous Warehouse Configuration

In this section we will go on to analyze the pre-existing configuration of the plant's packaging warehouse, paying particular attention to the critical management and operational inefficiencies that necessitated the optimization and redesign intervention as part of the thesis project. The study will focus on the organization of space, how the pallets are stored, and the main problems encountered, with particular emphasis on the areas with the greatest impact in terms of time and operational costs. Ineffective management of available space and haphazard allocation of materials, lacking structured logic and functional subdivisions, have resulted in prolonged search times and excessively long routes for transferring materials from the warehouse to production lines, negatively affecting the overall efficiency of the logistics process. These factors had direct repercussions on productivity, generating delays in the packing and packaging of finished products and, consequently, in the supply of the shipping area.

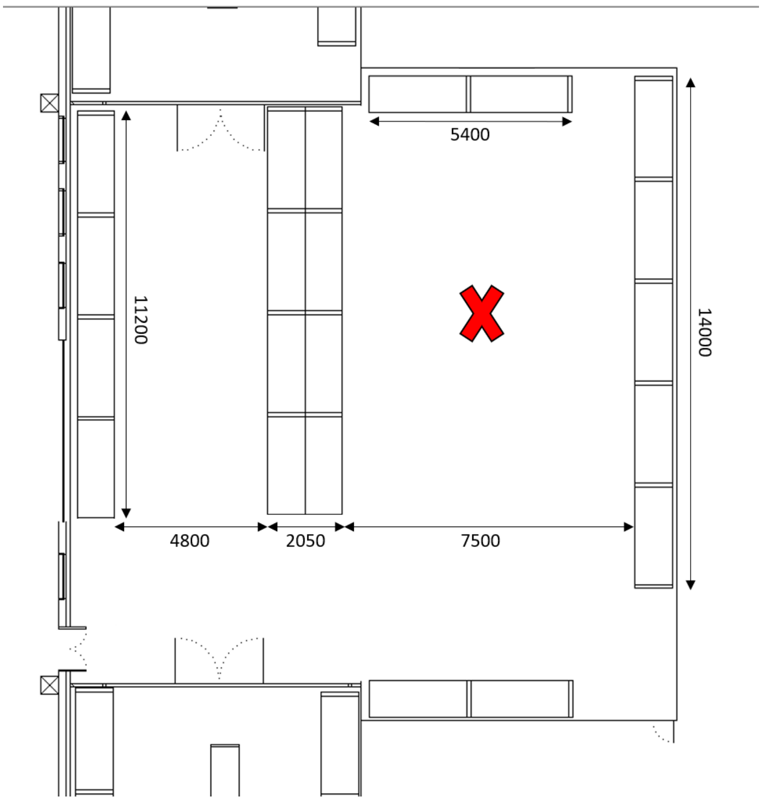

Figure 4.3: Packaging Warehouse layout before intervention

Looking at the floor plan of the warehouse dedicated to packaging, some issues related to the arrangement of shelves and utilization of available space clearly emerge. The total area of the area under consideration is about 285 m^2, but with the pre-existing configuration, the total footprint of the shelving is limited to only 60 m^2, resulting in a saturation level of 20%. The warehouse is equipped with 84 storage cells, arranged on four levels and divided into 21 horizontal columns. However, the allocation of shelving was not optimally designed, leaving vast portions of unused space that could have been allocated for additional packaging storage or the

reorganization of handling aisles.
A further obvious critical issue is the presence of informal storage areas (marked on the floor plan with the red symbol), where workers used to temporarily place pallets. This practice reduce a lot the efficiency pof the entire system, and also it should compromises the operator safety due to poor visibility of materials and the risk of accidental collisions with equipment. Thus, due to poor management system, nonvalue-added activities could increase cionsequentely, negatively impacting the operational timelines and the business costs.

Figure 4.4: Warehouse pre-intervention

A more in-depth analysis of internal material handling, conducted using a spaghetti chart, revealed further inefficiencies related to the routes followed by forklift drivers to transport packaging to the production lines. Observation of handling flows identified excessively long and circuitous routes, caused by non-rational racking layouts and the lack of optimized routes for the transit of handling equipment. In particular, it was found that, in order to reach certain storage positions, operators were forced to travel considerable distances, unnecessarily increasing transfer times and reducing the overall productivity of the warehouse.
The lack of standardization of locations and a clear system for identifying materials further exacerbated the problem, generating difficulties in finding components and inconsistencies between the actual location of platforms and the information reported in management systems. The lack of an unambiguous method for locating materials necessitated continuous manual verification operations, slowing the flow of activities and increasing the risk of errors. From an economic point of view, the inefficiencies found resulted in increased operating costs, mainly due to increased material search times and longer handling routes. The impact of these issues is reflected not only on the efficiency of logistics personnel, but also on the smoothness

of the entire production process, directly affecting delivery times and the ability to respond quickly and flexibly to production needs.

The analysis of the critical issues that emerged therefore demonstrates the need for a redesign of the warehouse layout, aimed at improving the use of available space, reducing handling times and increasing the safety and efficiency of logistics operations. The next section will discuss the new configuration implemented and the strategies adopted to solve the issues highlighted, with the goal of transforming the warehouse into a structured, efficient environment that complies with the principles of Lean Manufacturing.

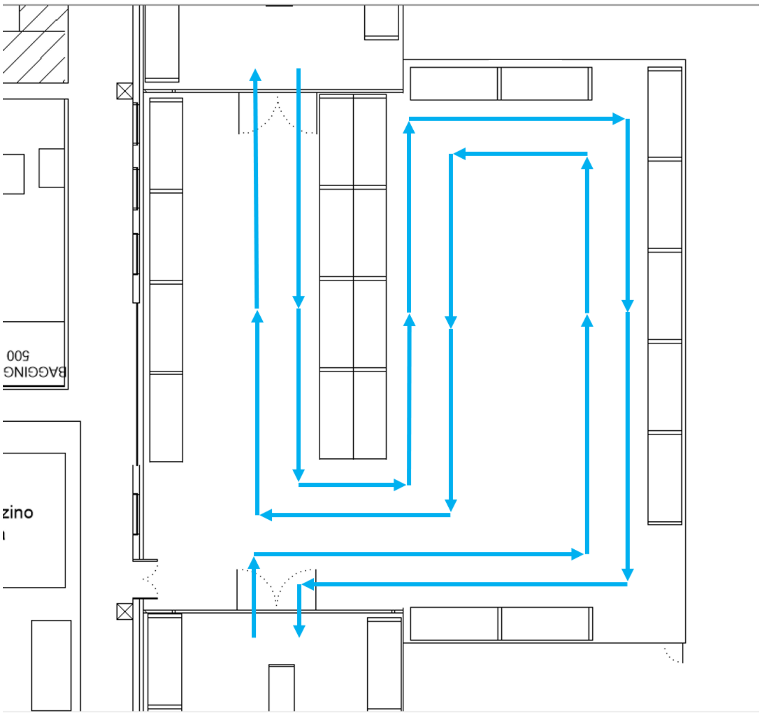

Figure 4.5: Material handling main pre-existing flows

An additional area of the warehouse that is of particular interest in the analysis of the past state is the area designated for the storage of the dies used in the presses and work-sheets, as well as the racks dedicated to the platforms used for the packaging of finished products. Observation of the warehouse floor plan clearly shows how space management, particularly in the left portion of the storage area, has significant room for improvement in terms of organization and efficiency.
One of the main critical issues in this area is the presence of an outdated door, unused for several years and yet still present in the warehouse structure. Failure to permanently close this access generates problems from both an operational and security point of view, since the disused gateway can be a source of misunderstanding and interference in daily activities. The elimination of this structural element, which will be explored in more detail in the following sections devoted to interventions to improve and optimize the pre-existing layout, would allow a more rational use of the available space. In fact, the removal of the door would allow the installation of additional shelving, developed both horizontally and vertically, resulting in increased storage capacity and better distribution of materials.

Another important point to consider is the existence of two areas on the floor plan marked with a blue 'X' symbol. Right now, these spots don't have any shelving and are cluttered with outdated materials, like old production machine molds and various components that are no longer in use. This haphazard storage not only wastes valuable floor space but also hampers the overall efficiency of our warehouse.

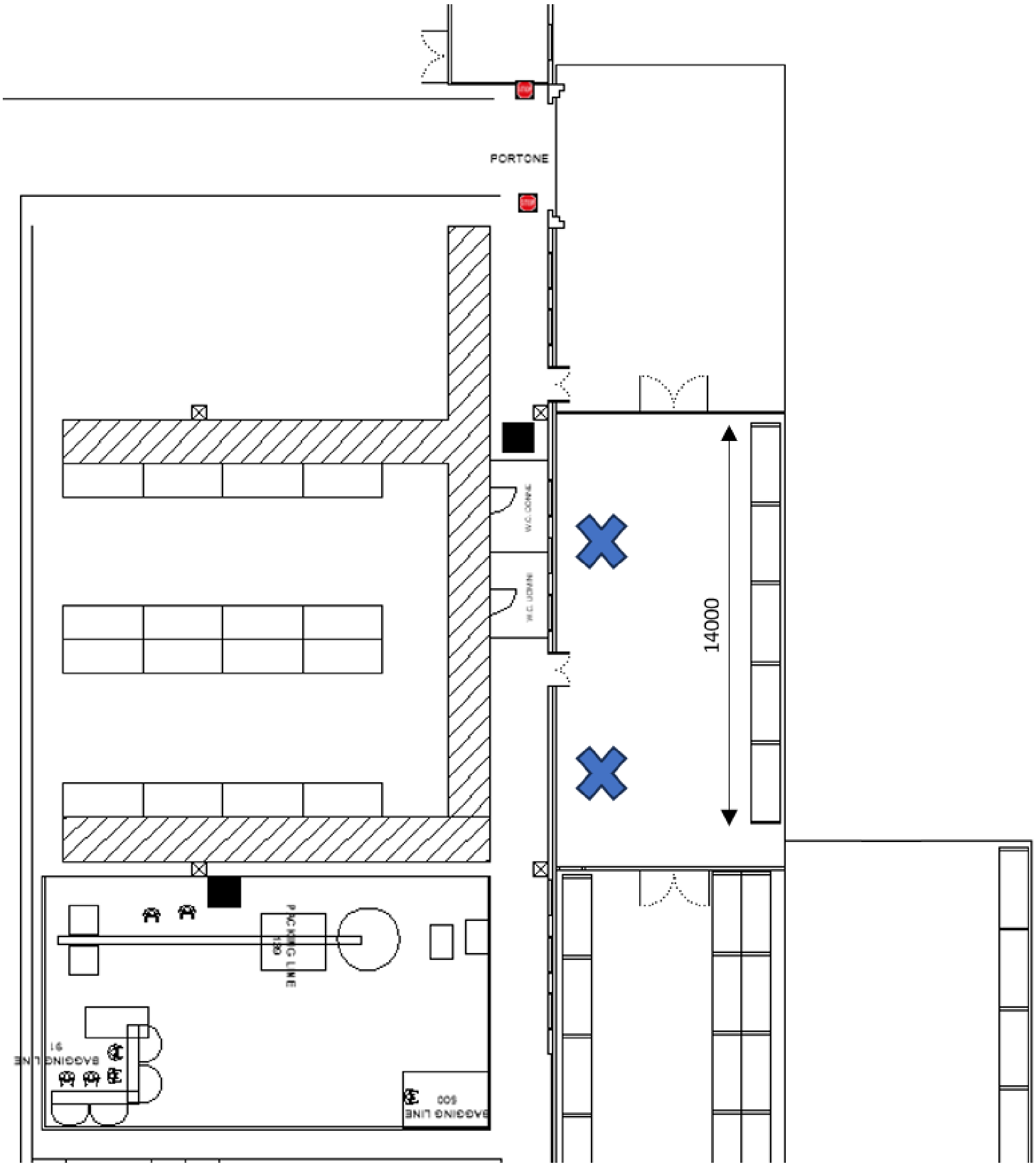

Figure 4.6: Pre-existing Area for dies

Another important issue it's the management of empty pallets. Now, they're stored all over the place without any clear system, making it tough to access the racking. This chaos leads to delays when we're trying to pick materials and search for items, slowing down our overall warehouse productivity. Plus, the way these pallets are stacked isn't very safe, either—it increases the chance of accidents, whether it's from toppled stacks or obstacles blocking the paths for forklifts and operators.

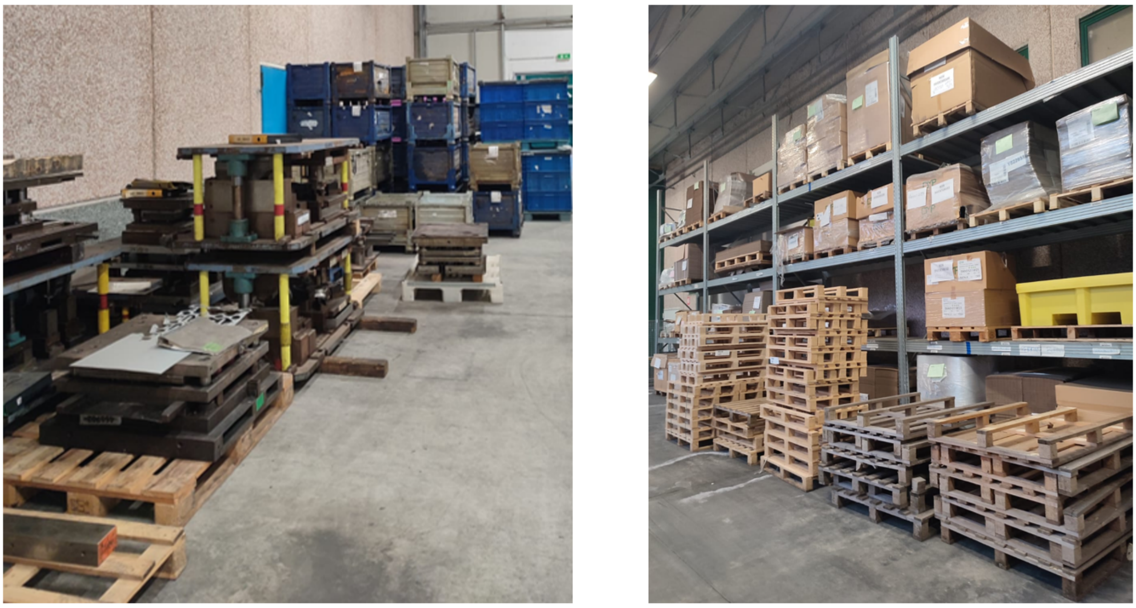

Figure 4.7: Current-State for Dies and Storage of Pallets

In light of this evidence, there appears to be a clear need for remediation and redesign of the area, aimed at eliminating unused elements and optimizing space layout. A rationalization of the logistical organization of the warehouse would not only increase storage capacity, but also improve safety and operational efficiency by reducing search and material handling times. The following sections will detail the strategies adopted to solve these critical issues, with the goal of transforming the warehouse into a more structured, efficient environment that conforms to the principles of streamlined and optimized management.

4.3 Packaging Warehouse Layout Redesign

This section is devoted to the redesign of the warehouse layout with the aim of significantly improving efficiency in managing available space and optimizing the storage logic of materials on the racks. The optimization intervention resulted in significant logistical benefits, including a clearer and more orderly arrangement of packaging codes, more efficient saturation of available space, and a significant improvement in the routes followed by warehouse workers during each shift to replenish the production lines with the correct packaging for finished goods.
The analysis of the solution proposed in this thesis project focuses on the redesign of the layout of the warehouse area for packaging. In contrast to the previous configuration, the new layout, as highlighted in the floor plan shown on the right, allowed for an increase in the space allocated to material storage while keeping the total warehouse area unchanged. This intervention led to a substantial improvement in storage capacity, since, while starting from a 285 m^2 area, as many as 16 new storage cells were added, bringing the total to 25 horizontal cells (standard shelving dimensions: 2700 x 1000 mm). Considering the vertical development of shelving on four levels, the total number of storage units increased to 100, thus ensuring more efficient space management, which reached a saturation of 25%, or 72 m^2.

In terms of numbers, the move from the previous arrangement of 21 racks to the current configuration with 25 units has resulted in a significant increase in storage capacity. Thanks to the four-level layout and the ability to accommodate up to three lettings per rack (size 900 x 1000 mm), the total number of available cells has increased by 48 units. This result, achieved without an increase in the overall warehouse area, represents a significant improvement in efficiency, with a 20% increase in the storage capacity of the pallets containing packaging for finished goods.

By optimizing our layout, we've made the best use of the space we have, which has really boosted how our warehouse runs. With the added storage capacity, we don't have to move pallets around as often, cutting down on downtime and unnecessary journeys. Plus, the new rack layout has optimized our workflows, making everything run more smoothly. Overall, this new setup has not just made managing the warehouse easier, but it's also helped us lower our operating costs. It really shows how important it is to customize layouts to fit our production and logistics needs.

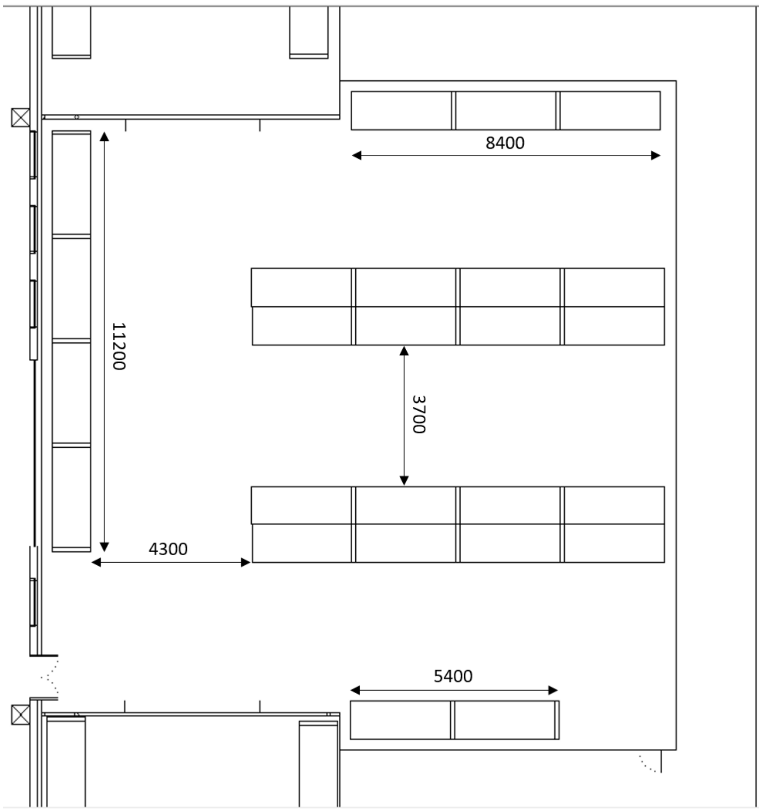

Figure 4.8: Re-design of Packaging Internal Warehouse

The implementation of the new layout also allowed for the elimination of temporary storage areas for materials that previously posed a significant risk to operator safety. The removal of cluttered storage areas resulted in a more orderly and safer work environment, providing direct and immediate access to the racks. This prevented materials and platforms from being left in the aisles, improving operational safety and visual management of the warehouse. In fact, space optimization has dramatically reduced the risk of accidents, improving the smoothness of handling operations and reducing the time it takes to search for and retrieve materials.

Another key aspect of the redesign involved the in-depth study of aisle widths so that they would allow warehouse workers and forklift drivers to maneuver safely. Optimizing the size of the aisles allowed more ergonomic and quicker access to materials, reducing non-value-added activities, such as inefficient searching for storage codes, which in the past generated delays and operational difficulties. Updating the shelving layout and improving internal signage also helped reduce picking errors, making the entire logistics process smoother and more efficient.

Figure 4.9: New layout configuration

As shown in the figure below, the project also included the reorganization of material handling flows within the warehouse. Analysis using 'spaghetti charts' showed that the new layout enabled faster and safer picking, reducing the number of unnecessary trips and improving overall efficiency. Unlike the previous configuration, in which operators were forced to walk through the entire warehouse in search of needed material, the new system allows for quick identification of storage locations due to a more logical and rational layout. This has resulted in significant time savings in both travel and material search times, with obvious benefits to productivity and safety.
Flow optimization has proved particularly effective even in worst-case scenarios, as demonstrated in the analysis of the most critical scenario ('worst scenario'), in which a warehouse worker has to pick up pallets located in four different areas of the warehouse. Compared with the previous configuration, in which such operations were chaotic and time-consuming, the new arrangement allows for path minimization, making the task faster and more efficient.

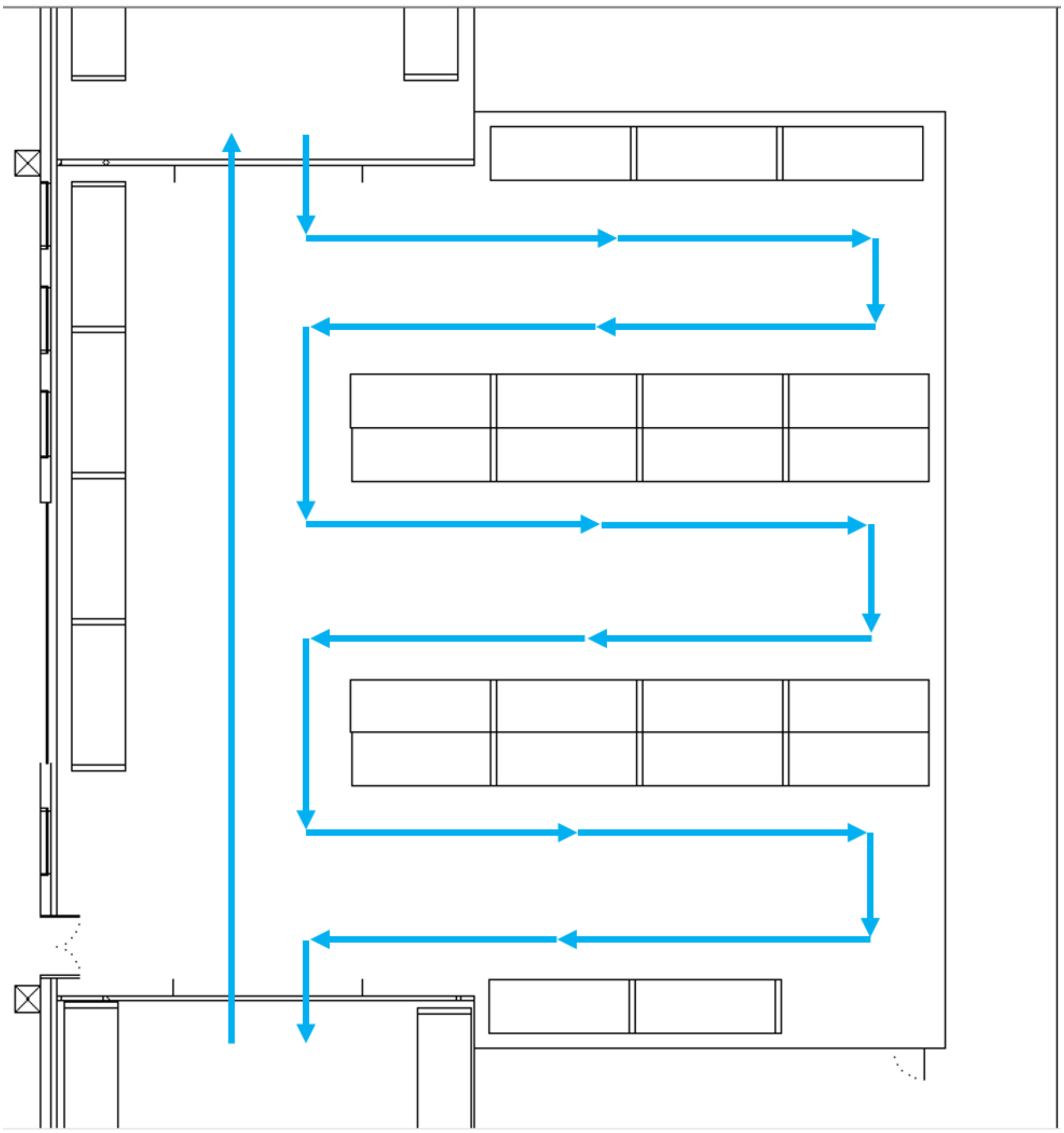

Figure 4.10: Optimization of Material Handling flows

Next, a second area of the warehouse was analyzed, intended for the storage of molds and racks for packaging platforms. After a joint analysis with the safety department, it was decided to permanently close an old, disused doorway by means of a concrete pour, thus creating a continuous wall. This operation made it possible to eliminate a potentially dangerous area and, at the same time, to use the space more efficiently, allowing the installation of new shelving without structural or accessibility constraints.

As evidenced by the floor plan shown in the figure below, the new configuration made it possible to add five additional standard shelving units (2700x1000 mm) along the left side of the warehouse. This intervention optimized the use of space not only horizontally, but also vertically, allowing for the best use of the available volume. Thanks to this solution, it was possible to improve the order and arrangement of the platforms and molds, previously placed haphazardly on the floor, generating clutter and hindering handling operations. The addition of the new racks allowed for a further increase of 60 storage cells, a result achieved by developing the five racks on four vertical levels and accommodating up to three pallets on each level (dimensions 800x1000 mm). This increase in storage capacity was a significant benefit, allowing for reduced clutter, improved accessibility to materials, and ensuring more effective warehouse management.

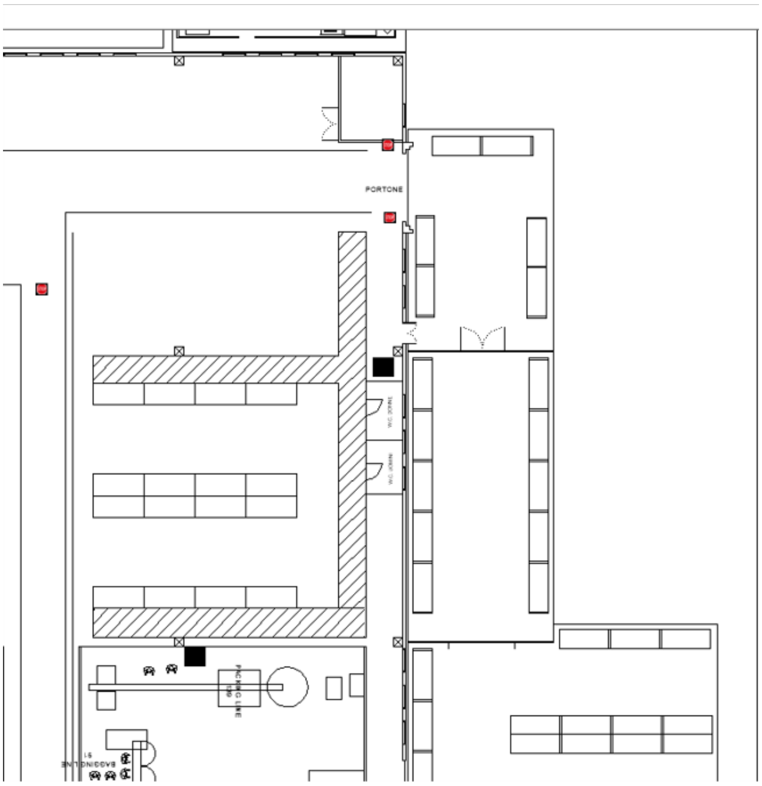

Figure 4.11: New layout for Dies Warehouse

Together, these interventions have achieved a significant improvement in logistical efficiency, reducing handling and picking times, increasing operator safety, and ensuring more rational management of available space. Optimization of the layout, combined with better organization of storage logics, has thus made it possible to transform the warehouse into a tidier, safer and more efficient environment, with tangible benefits in terms of both productivity and reduced operating costs.

4.3.1 Reorganization of Shelving

In this section, the space management obtained as a result of the redesign of the warehouse layout will be analyzed, with particular attention to the organization of the storage of packaging pallets. Prior to the reorganization, the layout of the pallets and their codes was extremely haphazard, lacking a logical structure that would allow for quick and effective identification of materials. The lack of a clear classification criterion resulted in numerous inefficiencies, including difficulties in finding the correct material, errors in picking, and delays in handling operations, with a consequent negative impact on warehouse productivity.
The introduction of a new layout made it possible not only to increase the number

of cells available for storage, but also to develop a more rational and efficient strategy for the arrangement of pallets and related codes. The reorganization aimed to make it easier and quicker for everyone to access materials, cutting down on search times and enhancing the overall warehouse operations. To reach these goals, we introduced a new classification system based on two main criteria, which I'll examine more in the following paragraphs.
A key aspect of the new storage methodology was the introduction of a shelving labelling system. Each was assigned a unique identifying letter so as to eliminate any ambiguity and make the location of the material immediate. This expedient made it possible to simplify picking and replenishment operations, significantly reducing the risk of errors and optimizing operators' routes within the warehouse. As can be seen in the figure below, the new arrangement has made the naming and identification of racks clearer, facilitating warehouse management and ensuring greater efficiency in logistics operations.

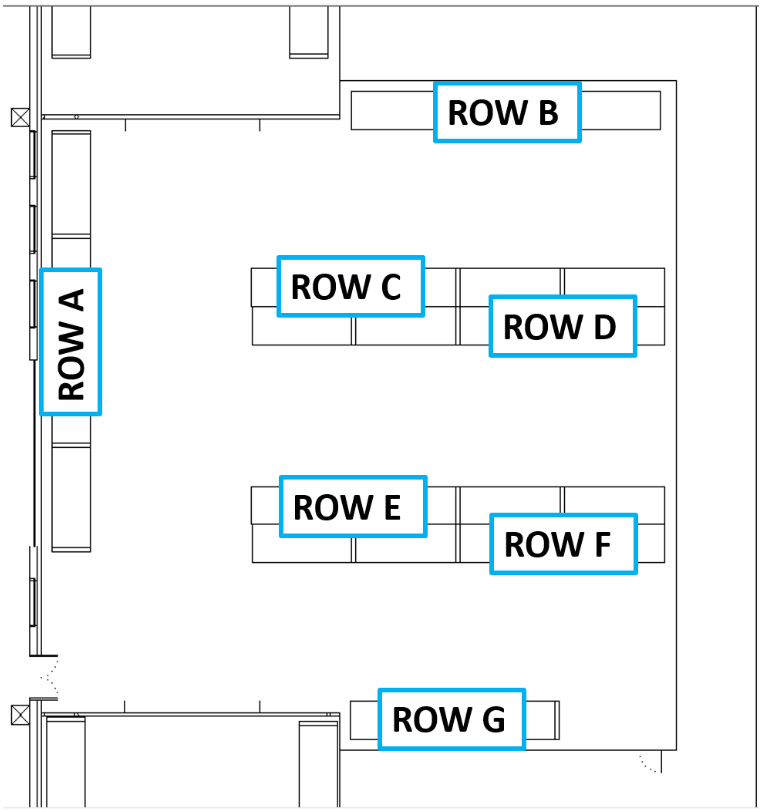

Figure 4.12: New Layout - Rows configuration

In addition to numbering and labelling the racks, a storage logic was adopted that takes into account the frequency of platform use and the specific needs of production. Materials with high turnover were placed in easily accessible areas, minimizing picking times and reducing unnecessary operator trips. Conversely, less frequently used pallets were placed in less strategic areas, but still organized according to a precise criterion that allows their quick retrieval when needed. This subdivision has made the handling process smoother, avoiding congestion in the aisles and improving the overall safety of the work environment. Finally, the implementation of this

new storage strategy has led to a significant improvement in the visual management of the warehouse, making the location of each code immediately recognizable. This has led to a reduction in material search time and an increase in operational efficiency, with positive effects on the overall productivity of the logistics department as well. Thus, the combination of an optimized layout, a clear labelling system, and a layout based on well-defined logistical criteria made it possible to transform the warehouse into a more orderly, safe, and efficient environment, contributing to the overall improvement of workflow and the reduction of operational inefficiencies.
Following the redesign of the warehouse layout, a logical and systematic subdivision of the 42 codes related to the pallets intended for packaging became necessary in order to ensure more efficient management and minimize the risk of errors in material picking. The new organization strategy was based on dividing the codes into four main categories, each corresponding to a different production department in the plant. This approach made it possible to optimize the flow of pallet handling, ensuring that each packaging material was strategically placed and easily found by operators.

- GASKET-EMG

This document shows 17 codes related to packaging materials specifically designed for finished products coming from the GASKET and EMG departments. These materials consist of cardboard boxes, box lids, protective bags, bubble wrap, and other essential items needed to ensure proper handling of the final packaging. The layout of these materials is carefully arranged to reduce picking times and guarantee that each department can access the materials they need efficiently, without disrupting other production processes.

CODICI	DESCRIPTION	THROUGHPUT	DEPARTMENT
SXA515201024	PACKBOL 30X37	HIGH	GASKET-EMG
SXA71KT5201007	SCAT.IMB.34X20X13,7	HIGH	GASKET-EMG
SXA71KT5303010	SCAT.IMB.41X31X16,5	HIGH	GASKET-EMG
SXA71KT5200254	SCAT.NEUT.425X190X85	HIGH	GASKET-EMG
SXA715300097	Scatola fustellata 32X20X10	HIGH	GASKET-EMG
SXA71KT5301046	SEPARATORE IMB 160x240	HIGH	GASKET-EMG
SXA515208087	Versandkarton Ford IMC 050	HIGH	GASKET-EMG
SXA71KT5301048	Coperchio fustellato 300x200x50	MEDIUM	GASKET-EMG
SXA71KT5301050	Coperchio fustellato 400x300x50	MEDIUM	GASKET-EMG
SXA71KT5301052	Coperchio fustellato 470x320x50	MEDIUM	GASKET-EMG
SXA71KT5301047	Scatola fustellata 300x200x100	LOW	GASKET-EMG
SXA71KT5300103	Scatola fustellata 31X20X6	LOW	GASKET-EMG
SXA71KT5301056	Scatola fustellata 400x300x100	LOW	GASKET-EMG
SXA71KT5301049	Scatola fustellata 400x300x150	LOW	GASKET-EMG
SXA71KT5301055	Scatola fustellata 400x300x200	LOW	GASKET-EMG
SXA71KT5301051	Scatola fustellata 470x320x120	LOW	GASKET-EMG
SXA515208088	Versandkarton Ford IMC 090	LOW	GASKET-EMG

Figure 4.13: Gasket and EMG codes

- INJECTION-UNIPISTON

It includes 13 packaging material codes used for finished products in the Injection and Unipiston departments. Again, the classification was based on intended use, allowing the material to be divided rationally and simplify picking operations. Materials included in this category include cardboard boxes of various sizes, component trays, bags and spacers, all of which are essential to ensure the proper protection and storage of products leaving the aforementioned departments.

CODICI	DESCRIPTION	THROUGHPUT	DEPARTMENT
SXA512118032	VASSOIO 13 SEDI PER SXA112210035	HIGH	INJ.-UNIPISTON scarico carrini
SXA512118033	VASSOIO 13 SEDI PER SXA112210036	HIGH	INJ.-UNIPISTON scarico carrini
SXA512118034	VASSOIO 13 SEDI PER SXA112210037	HIGH	INJ.-UNIPISTON scarico carrini
SXA512118031	VASSOIO 6 SEDI PER SXA112210034	HIGH	INJ.-UNIPISTON scarico carrini
SXA512118028	PLASTIC TRAY MX13 LARGE (1876190)	HIGH	INJ.-UNIPISTON x COATING
SXA512118027	PLASTIC TRAY MX13 SMALL (1876189)	HIGH	INJ.-UNIPISTON x COATING
SXA71KT5201014	SCAT.CARTONE 5201014 53.5x35X19,6	HIGH	INJ.-UNIPISTON x REINZ
SXA71KT5204114	ALVEARE 6 POS. X SCATOLA 5200171	HIGH	INJ.-UNIPISTON x SUZUKI
SXA71KT5200171	SCAT. 358X290X202	HIGH	INJ.-UNIPISTON x SUZUKI
SXA71KT5303000	SCAT.FIAT 62X41X17,5	MEDIUM	INJ.-UNIPISTON x BRASILE
SXA512118030	PLASTIC TRAY MX11 LARGE (1923380)	MEDIUM	INJ.-UNIPISTON x COATING
SXA512118029	PLASTIC TRAY MX11 SMALL (1923376)	MEDIUM	INJ.-UNIPISTON x COATING
SXA515202062	Scat. dim. 400 x 300 x H310 (maniglie)	LOW	INJ.-UNIPISTON x BMW,con GLITTER BOX

Figure 4.14: Injection and Unipiston codes

- ALL DEPARTMENTS

It includes 12 codes related to packaging materials used crosswise by all departments in the plant. Their peculiarity lies in the fact that, since they are not intended for one specific department, they must be easily accessible from any production area. For this reason, a strategic storage solution was adopted, locating these platforms in the central portion of the warehouse, along the main aisle. This choice made it possible to minimize operator movements, ensuring faster picking operations and facilitating the management of material requests in real time.

CODICI	DESCRIPTION	THROUGHPUT	DEPARTMENT
SXA73KT5301043	IMB.COPERCHIO 1406X1803	HIGH	ALL
SXA73KT5301042	SEPARATORE IMB.1150X780	HIGH	ALL
SXA73KT5301045	SEPARATORE IMB.800X800	HIGH	ALL
SXA515200365	BOARD KTM 220X275	HIGH	ALL
SXA51700026L	BOARD NEUTRAL WHITE 220X490	HIGH	ALL
SXA73KT5301041	IMB.1009 1200X800X870	HIGH	ALL
SXA515200181	BOARD CNH 270X690	MEDIUM	ALL
SXA515305003	BOARD NEUTRAL WHITE 370X738 MS-500-002 -	MEDIUM	ALL
SXA71KT5303001	CART.NEUTRO X IMB.46,5X30	MEDIUM	ALL
SXA515208085	distanziatore	LOW	ALL
SXA71KT5301023	IMB.61X40X35 MARCATO	LOW	ALL
SXA71KT5301063	PEDANE DI LEGNO		ALL

Figure 4.15: General codes of All Departments

- OBSOLESCENCE

It consists of packaging materials that are no longer used in production processes. Currently, there are up to 16 codes of pallets containing obsolete materials in the packaging warehouse, accounting for about 27.5% of the total number of pallets used for packaging finished products. The presence of these unused materials generates unproductive space occupancy, limiting storage capacity for materials actually needed for production and shipment. To solve this problem, a temporary area has been established for the grouping of these obsolete pallets, pending disposal or resale. The long-term goal is to free up useful space for the introduction of new packaging materials, avoiding waste and ensuring a more rational use of available resources within the warehouse.

CODICI	DESCRIPTION
SXA512118004	VASSOIO 8 SEDI X 2210501
SXA512118005	VASSOIO 8 SEDI X 2210502
SXA512118006	VASSOIO 10 SEDI X 2210504
SXA512118007	VASSOIO 4 SEDI X 2210505
SXA512118008	VASSOIO 4 SEDI X 2210506
SXA515200126	BOARD LOMBARDINI 260X330
SXA515200167	BOX LOMBARDINI 260X500X25
SXA515200168	BOX LOMBARDINI 260X380X20
SXA515200293	BOARD IVECO 275X710 -EB-
SXA515200359	BOX FIAT 260X500X30 (5759)
SXA515200370	BOARD KTM 245X400
SXA515200390	BOX FIAT 400X550X30 (7760)
SXA515200391	BOARD FIAT 180X400 (7859)
SXA515201003	SCAT.IMB.47X30,5X11
SXA51Y822851	BOARD PERKINS 228X580
SXA51Y822853	BOARD PERKINS 228X810 -EB

Figure 4.16: Obsolete codes

In addition to this subdivision, detailed mapping of storage locations was implemented and shown in the updated warehouse layout plan. As a result of this new organizational logic, warehouse management has become significantly more efficient, with a reduction in the average time required for picking operations and increased safety in handling pallets. In addition, space optimization has improved the ergonomics of workstations, reducing the need for unnecessary movement and minimizing the risk of operational errors.

In addition to the division of packaging materials according to their intended use in the various production departments, an additional classification criterion adopted was that based on frequency of use. This approach made it possible to further optimize the layout of the pallets, ensuring strategic placement that minimized picking times and improved operational efficiency. For each material code, the frequency of use was calculated on a monthly basis, analyzing an entire working year in order to obtain reliable data representative of actual production needs.

Based on this data, the materials were divided into three main categories:

- High rotating;
- Medium rotating;
- Low rotating.

High rotating materials are those that get used most frequently. Because of this, warehouse workers need to pick them up often to keep production lines running smoothly. To make things easier, we decided to store these items on the first level of the racks. This setup gives workers quick access to the materials, which cuts down on picking times and reduces needing extra lifting—a big win for both ergonomics and safety. By placing these items at the bottom of the warehouse, operators can grab them quickly without having to use additional lifting devices, which speeds up the whole logistics process.

Medium rotary materials aren't used as frequently as high rotary ones, but they still play a key role in production. We've decided to store these materials mainly on the second level of the racking system. This setup strikes a balance between easy access and making the most of our space. While it's not important for these materials to be right at the bottom, we want to make sure that our warehouse workers can reach them easily with forklifts. By placing them here, we find a good compromise between working efficiently and using our vertical space wisely.

So, we've put the **low-rotation materials**—those items that don't get picked very often—up in the upper levels of the warehouse. Since these are only used occasionally, we didn't mind putting them in harder-to-reach spots. The picking process for these materials does take a bit longer compared to the high and medium rotation items, but since they're not used frequently, that difference isn't a big deal. This way of organizing things helps us make the most of our space without messing up the daily picking and stocking process.

The implementation of this new classification logic has resulted in a significant improvement in warehouse management. Thanks to the combination of the subdivision by macro-areas (GASKET-EMG, INJECTION-UNIPISTON, ALL DEPARTMENTS, OBSOLESCENCE) and categorization by frequency of use (high rotating, medium rotating, low rotating), it has been possible to achieve an optimized shelving layout, reducing wasted time and improving operational safety. The new configuration also promoted greater visibility and traceability of materials, reducing the risk of picking errors and simplifying inventory operations.

The next section will detail the process of studying and implementing the new racking configuration, analyzing how the combination of the two categorization logics helped improve the overall efficiency of the logistics system and make the flow of materials within the warehouse smoother and more rational. Comparative analyses between the previous layout and the optimized layout will also be presented, focusing on the measurable impacts in terms of reduced handling time, increased storage capacity and improved operational safety.

4.3.2 Allocation of Racks

The reorganization of the warehouse layout included an optimized allocation of racks, subdividing the different rows according to the type of materials stored and their intended use in the various production departments. This new configuration made it possible to improve not only the management of available space, but also the efficiency of picking and replenishment operations, reducing wasted time and increasing operator safety.

- **Row A - ALL DEPARTMENTS**

Row A has been exclusively dedicated to the storage of pallets containing packaging materials used crosswise by all production departments. Given their strategic importance for replenishing the entire plant, a storage logic was adopted that took into account the frequency of use of material codes. Specifically, as illustrated in the figure below, the first level housed the platforms containing high-rotating materials, which were easily accessible and quickly picked up by operators. Continuing to the upper levels, there are the medium-rotating materials, located on the second level, while the fourth and final level houses the low-rotating materials, which are characterized by a low frequency of use, often on a monthly or even annual basis. This configuration reduces search and retrieval times, improving ergonomics and safety in the warehouse.

	1	2	3	4	5	6	7	8	9	10	11	12
A04	SXA71KT5301023						SXA515208085					
A03	SXA71KT5303001				SXA515305003				SXA515200181			
A02	SXA73KT5301045		SXA73KT5301042		SXA73KT5301041		SXA51700026L		SXA515200365		SXA73KT5301043	
A01												

Figure 4.17: Packaging codes configuration for Row A

- **Row B - OBSOLESCENCE**

Row B is set aside just for temporarily storing pallets filled with outdated materials, like packaging codes that we no longer use in production. We created this section of the warehouse to keep all those obsolete materials in one spot while we figure out what to do with them—whether that's reselling or getting rid of them. This way, we can clear up space in other parts of the warehouse, making sure that materials we actually need don't get mixed up with what's no longer useful. Plus, having a special area for these outdated items helps us keep a closer eye on what needs to be reclaimed, which makes planning for disposal a lot easier.

	1	2	3	4	5	6	7	8	9
B03	SXA51Y822853	SXA51Y822851	SXA515201003	SXA515200391		SXA515200390		SXA515200370	
B02	SXA515200359	SXA515200293		SXA515200168		SXA515200167		SXA515200126	
B01	SXA512118008	SXA512118007		SXA512118006		SXA512118005		SXA512118004	

Figure 4.18: Obsolete codes configuration of Row B

- **Rows C and D - GASKET & EMG**

Rows C and D were intended for the storage of pallets related to packaging materials used in the GASKET and EMG production departments. In this case, in addition to division by department, a classification criterion based on frequency of use was adopted, but with a different approach than that used for Row A. From the results obtained through an analysis of picking times, it was decided to change the strategy of material placement: instead of sorting materials by shelf level, a placement logic was adopted in relation to distance from the main aisle. Specifically, high-rotating materials were placed in the sections closest to the aisle, thus providing faster access and reducing the distance travelled by operators for picking. Low-rotating materials, on the other hand, were placed in the innermost and least accessible part of the rack, as they are handled less frequently. This strategy proved to be more effective than the one adopted in Row A, as it resulted in a significant reduction in the travel time of warehouse workers during picking and replenishment operations, improving overall productivity.

<table>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th></tr>
<tr><td>C04</td><td colspan="3" rowspan="2">SXA515201024</td><td colspan="3" rowspan="2">SXA515208087</td><td colspan="3" rowspan="2">SXA71KT5300103</td><td colspan="3" rowspan="2">SXA71KT5301049</td></tr>
<tr><td>C03</td></tr>
<tr><td>C02</td><td colspan="3" rowspan="2">SXA71KT5200254</td><td colspan="3" rowspan="2">SXA715300097</td><td colspan="3" rowspan="2">SXA71KT5301047</td><td colspan="3" rowspan="2">SXA515208088</td></tr>
<tr><td>C01</td></tr>
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<table>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th></tr>
<tr><td>D04</td><td colspan="3" rowspan="2">SXA71KT5301046</td><td colspan="3" rowspan="2">SXA71KT5301048</td><td colspan="3" rowspan="2">SXA71KT5301052</td><td colspan="3">SXA71KT5301056</td></tr>
<tr><td>D03</td><td colspan="3">SXA71KT5301055</td></tr>
<tr><td>D02</td><td colspan="3" rowspan="2">SXA71KT5201007</td><td colspan="3" rowspan="2">SXA71KT5303010</td><td colspan="3" rowspan="2">SXA71KT5301050</td><td colspan="3" rowspan="2">SXA71KT5301051</td></tr>
<tr><td>D01</td></tr>
</table>

Figure 4.19: Gasket and EMG configuration of Rows C and D

- **Rows E and F - INJECTION & UNIPISTON**

For Rows E and F, containing the platforms relating to packaging materials destined for the Injection and Unipiston departments, a similar criterion was adopted as for Rows C and D. Again, materials were divided according to their frequency of use, but their allocation was organized by considering their distance from the main aisle, rather than their vertical arrangement on the racks. High-rotating materials were thus placed in the areas closest to the access and transit points, reducing the time required to pick them up, while low-rotating materials were placed in the innermost areas of the racks. This choice made it possible to optimize the internal handling flow, reducing interference between logistics flows and improving the overall management of available space.

<table>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th></tr>
<tr><td>E04</td><td colspan="3" rowspan="4">SXA512118027</td><td colspan="3" rowspan="4">SXA512118028</td><td colspan="3" rowspan="4">SXA512118031</td><td colspan="3" rowspan="2">SXA515202062</td></tr>
<tr><td>E03</td></tr>
<tr><td>E02</td><td colspan="3" rowspan="2">SXA71KT5303000</td></tr>
<tr><td>E01</td></tr>
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<table>
<tr><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th></tr>
<tr><td>F04</td><td colspan="3" rowspan="2">SXA71KT5200171</td><td colspan="3" rowspan="2">SXA71KT5201014</td><td colspan="3" rowspan="2">SXA71KT5204114</td><td colspan="3" rowspan="2">SXA512118030</td></tr>
<tr><td>F03</td></tr>
<tr><td>F02</td><td colspan="3" rowspan="2">SXA512118032</td><td colspan="3" rowspan="2">SXA512118033</td><td colspan="3" rowspan="2">SXA512118034</td><td colspan="3" rowspan="2">SXA512118029</td></tr>
<tr><td>F01</td></tr>
</table>

Figure 4.20: Injection and Unipiston configuration of Rows E and F

- **Row G - Storage Area for EUROPALLET**

Another major improvement introduced in the reorganization of the warehouse layout was the creation of an area dedicated exclusively to the storage of EUROPALLET's empty pallets. Before the intervention, these pallets were arranged haphazardly within the warehouse, occupying space not intended for their storage and creating obstacles in the aisles. This situation represented not only a space management problem, but also a potential safety risk for operators, who often found themselves having to manually move the platforms in order to access the materials stored in the racks. With the new configuration, a dedicated and well-defined area was created in which empty platforms are stored in an orderly and safe manner, avoiding clutter in the aisles and improving accessibility to other materials. This solution has reduced the risk of accidents, improved visual management of the warehouse, and speeded up the handling of empty pallets, which can now be easily picked up and used when needed.

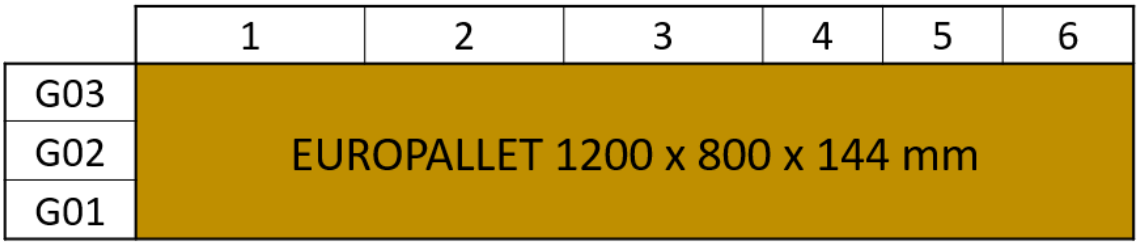


Figure 4.21: EUROPALLET New Configuration of Row G

The implementation of the new warehouse layout, with a rational subdivision of shelving and more efficient organization of space, has achieved several benefits in terms of optimizing storage capacity, reducing picking times, improving safety, and streamlining logistics flows. The adoption of dual classification logic–based on both the intended use of materials and their frequency of use–has enabled the design of a more functional and efficient system, reducing wasted time and improving overall warehouse productivity.
In the next section, the impact of these changes will be analyzed through a quantitative comparison between the previous and current configuration, evaluating the improvements achieved in terms of reduced distances travelled by operators, increased storage capacity and optimized internal handling flows.

4.3.3 Analysis of results

The new layout of the packaging warehouse has really paid off in many ways. With the updated racking system and a smarter organization of storage spots, we've been able to cut logistics costs considerably, optimize how we pick materials, and boost safety in the workplace.

One of the biggest challenges with the old system was how hard it was to locate pallets. The organization was poor, and there weren't clear criteria for classifying them. Logistics operators spent around ten minutes just trying to find one platform, which really adds up when they needed about 20 during each shift. With three

shifts per day from Monday to Friday (06:00-14:00, 14:00-22:00, 22:00-06:00) and an additional shift on Saturday (06:00-14:00), this amounted to handling about 15,000 pavements per year, with an expense in terms of search time of 2,500 hours per year. This translated into a cost to the company of about 25,000 euros per year, simply for the time lost in searching for material.
The optimization intervention reduced this time tenfold, bringing the search for a platform to just one minute. The new racking system, organized according to a clear and functional logic, made picking faster and more efficient. After a time, analysis conducted over a four-week period, it was possible to estimate that annually the time spent searching for materials was reduced to only 250 hours, saving about 22,500 euros. This means that 90 percent of the cost previously incurred has been eliminated, with a positive impact not only economically but also operationally. Operators can now focus on value-added activities, drastically reducing unnecessary operations and improving overall warehouse management.
A key aspect to consider is also the return on investment. The implementation of this new configuration involved an initial cost of 12,000 euros, due to the need to reorganize racking and rely on specialized suppliers to set up the new system. However, with the savings generated, in just six months the company fully recouped its investment and began to make a net profit soon after. The benefits of this operation, however, do not stop at just cost savings. The increased efficiency has led to better ergonomics for operators, reducing unnecessary travel and improving safety within the warehouse. The elimination of obstacles and the reorganization of space have reduced the risk of accidents and injuries, creating a safer and more orderly work environment. In addition, the new storage logic has improved the tracking of materials, facilitating the work of operators and further reducing downtime.

5 The 'Runner' Project: Optimization and Redesign of internal logistics flows

This final chapter will explore the work done during the five-month internship period at the Chivasso (TO) plant, focusing in particular on the analysis and optimization of internal logistics flows. The main objective of the project was to improve the efficiency of materials handling through the implementation of an internal milk-run system, a cyclic transport method that allows regular replenishment of production lines, optimizing time and resources.
During the project path, the support of the company and, in particular, of the company mentor Luis Felipe, who provided valuable advice and guidance, contributing significantly to the success of the analysis and its implementation, was essential. The first key step was to collect detailed data on logistics operations, analyzing how materials moved between the warehouse and production departments. This required extensive direct observation of the plants and a series of interviews with line operators and department managers. The survey revealed critical points in the existing logistics system, particularly inefficiencies related to inventory management, workstation layout and replenishment times for production lines.

One of the most critical aspects identified was the poor organization of space in production areas. The current configuration of the company layout does not facilitate the work of operators, particularly forklift drivers, who often find it difficult to intuitively recognize production lines and replenish them in a timely manner by milk-run. The presence of unnecessary materials and clutter at workstations further complicated the situation, making the procurement process inefficient and potentially dangerous. In fact, the passage of handling equipment is often obstructed by the presence of boxes and other materials left without a precise location, increasing the risk of workplace accidents and compromising operator safety.
Before implementing any improvements, it was therefore deemed necessary to carry out a preliminary upgrade of the production areas, aimed at ensuring greater order and cleanliness. A well-organized work environment not only reduces the risk of accidents, but also helps to improve operator productivity by eliminating wasted time related to searching for materials and space management.
Another key point that emerged from the analysis is the need to stabilize the pace of production to make internal flow management more efficient. When demand varies unpredictably, it becomes complex to ensure a constant and balanced supply of production lines. To address this problem, it is important to understand in detail the internal dynamics of production departments and adopt strategies that reduce the effects of demand fluctuations. Levelled production has many advantages: it optimizes resource use, reduces peak capacity demands, and ensures a smoother workflow. This leads to greater overall efficiency, which has a positive impact on business inventory management, lead time reduction and stable production volumes. In addition, a pull logic approach allows for increased operational flexibility, adapting the production process according to actual production needs.

Regarding internal logistics, the procurement system is currently based on a milk-run model, in which an operator periodically walks through the production area to pick up empty containers and evaluate any specific requests from the team leaders in charge of the various locations. This system, although advantageous, has some critical issues, particularly with regard to managing information on stock levels. Communication between material handlers and production staff is not always clear and structured, and this can lead to situations of misalignment between the real needs of production and the availability of materials in the warehouse.

One of the most significant problems concerns the untracked picking of small parts, which can cause sudden stock breaks, putting production continuity at risk. Therefore, it is necessary to implement a more accurate and reliable monitoring system that provides a clear view of inventories and ensures timely and uninterrupted replenishment. The adoption of a more structured and optimized internal milk-run is an effective solution to improve the flow of materials between the warehouse and production. A well-designed system can reduce inefficiencies, improve inventory management and provide a safer and more organized work environment. Integrating digital information management tools and adopting Lean methodologies can further increase operational efficiency, making the system more responsive to production needs and improving the company's competitiveness in the long run.

5.1 Introduction

One of the most critical aspects affecting the efficiency of a production line is undoubtedly layout design. An ineffective layout can generate wasted time, increase unnecessary handling and make the flow of materials more complex than necessary, causing delays and reducing overall productivity. In contrast, an optimal layout of spaces and workstations allows for smoother movement of products between processing steps, improving ergonomics for operators and reducing wasted time due to unnecessary movement. Any activity that does not directly contribute to the creation of value for the customer represents a cost that the company must try to minimize, since the customer is not willing to pay for internal inefficiencies. Optimizing the production layout is a strategic activity for any production manager, as it allows minimizing the time spent on activities that do not generate value, while improving the overall efficiency of the process. For example, an incorrect layout of workstations can force operators to travel excessive distances or make repeated unnecessary movements, slowing the flow of production and increasing the risk of errors or accidents. In addition, if workstations are not organized according to a precise logic, machine setup and preparation times can expand unnecessarily, negatively affecting overall productivity.
An aspect often underestimated in layout design is the interaction between the flow of materials and the flow of operators. In many plants, it frequently happens that production workers have to interrupt their work to search for components or tools, thus slowing down the entire production process. By adopting an efficient milk-run system and a logical layout of stations, this problem can be solved, ensuring that each operator always has the materials he or she needs, without interruptions or downtime.

Another crucial point is the reduction of idle moves. Any internal movement that does not lead to product transformation represents a waste of time and resources. Optimizing the layout therefore means minimizing unnecessary internal transports, encouraging a continuous and linear flow of materials. This can be achieved through the use of well-defined lanes for goods handling, with clear and unobstructed routes, and through the integration of automated or semi-automated conveyor systems to reduce human intervention wherever possible. Finally, a well-designed production layout also contributes to improved workplace safety. Congested spaces, poorly designed handling routes, and haphazardly placed equipment can increase the risk of accidents and injuries. Implementing a more rational and orderly organization not only improves productivity, but also ensures a safer and more comfortable working environment for operators.

5.2 Hint at internal logistics flows

In recent years, optimization of internal logistics routes within companies has become a major issue, with a focus on efficiently managing the flow of materials between warehouses and production lines. Within an industrial environment, vehicles dedicated to transporting components must follow well-defined routes designed according to the configuration of the production layout in order to ensure a continuous flow free of inefficiencies. One key element to focus on is how we manage the milk-run system. This system is all about the regular transport of materials from the central warehouse to the different production points where they're needed. To make this process smoother, we often rely on automated trolleys or logistics trains made up of several cars. These handy tools create an efficient link between the warehouse and production departments, which helps cut down on replenishment times and simplifies the movement of materials.
To further improve the speed and accuracy of component distribution along the production line, it is common to integrate decentralized supermarkets into the system, which are intermediate storage areas where materials are accumulated and organized before their final destination. The effective design of these logistics flows requires a detailed analysis of the type of components being transported, the routes to be followed, and the frequency of replenishment, all of which are key to ensuring a constant and efficient supply of production lines. Accurate evaluation of these aspects also makes it possible to optimize the use of available space within the plant, reducing clutter and improving work ergonomics for operators. The adoption of standardized containers, selected according to the size and characteristics of the supermarket shelving, further contributes to smoother and more organized operations.

One of the key aspects for the success of an internal logistics system is the synchronization between route management and production planning, in order to ensure a smooth flow of materials and avoid situations of overstocking or component shortages. Thanks to the present study, it was possible to develop a dynamic route optimization model based on specific transportation and space constraints, demonstrating the importance of rational management of the means intended for servicing the line. In addition, it emerged how proper layout design can contribute to the reduction of Work In Progress by improving the rotation of components within supermarkets and minimizing waste. The strategic choice of supermarket racking location offers significant benefits in terms of inventory control and inefficiency reduction, turning the layout into a crucial element in the overall improvement of production performance.

The introduction of a replenishment system based on tense flows, fed by an internal milk-run, makes it possible to optimize warehouse space and reduce the amount of stock accumulated directly on production lines. This approach brings particularly effective results when coupled with a supermarket system with kanban

management, in which materials are replenished according to actual consumption. A popular methodology is the system that has two containers for each component: when one becomes empty, it is immediately replaced with the other, while the first is replenished in the warehouse. This mechanism makes it possible to reduce interruptions in production, ensuring a continuous flow of materials and a more rational use of logistical resources.
The implementation of this concept was of particular interest within the Chivasso (TO) plant, where it was applied to reorganize the supermarket dedicated to the Ass. P6 workstation components, located in the Heat Shield department. The adoption of a shelving system optimized for the supermarket allowed to improve the management of materials destined for this specific station, ensuring a faster and more efficient supply. In the following paragraphs, the improvements achieved through the inclusion of the new shelving system will be analyzed in detail, highlighting the benefits in terms of reduced waste, improved ergonomics and increased overall productivity of the work area.

5.3 Workstation Ass.P6 - Heat Shield Department

When it came to designing and setting up this shelved area, we needed to look at a few important things to make sure everything was organized well and that materials flowed smoothly. The first step was to map out the components in detail, sorting them based on their type and where they were going. After that, we put special identification labels on each packaging unit to help everyone recognize them quickly and cut down on any mix-ups. We also had to figure out the right number of totes and containers to keep things stocked up without letting materials pile up too much during production.
To create a production system that only brings in components as they're needed, we used a visual substitution technique. This approach really helped us cut down on the amount of materials on the production line, preventing overstocking, and making it easier to see what was being used each day. Previously, our warehouse faced quite a few issues because the materials on hand didn't always match what we actually used, often due to mistakes in allocation or damaged components. Thanks to this new setup, we've created a much clearer and efficient system for managing inventory, removing a lot of the uncertainties we had before.

Another crucial aspect of the project was the strategic location of the warehouse, positioned in an area adjacent to production. This choice was dictated by the need to reduce the distance between the warehouse, understood as the internal supplier, and the production line, which in this case represents the customer. A more direct connection between these two areas makes it possible to minimize transportation time and optimize the flow of materials, ensuring a faster and more continuous supply. The supermarket was built following the First In, First Out logic, ensuring that components are used on a first-in, first-out basis, thus avoiding the accumulation of obsolete stock or the risk of material deterioration. The gravity structure adopted for the racks allows for quick and efficient replenishment, with some locations dedicated exclusively to boxes intended for the replenishment phase. The latter phase has been particularly relevant for the management of small parts, for which suppliers often use wooden crates containing quantities of material in excess of weekly requirements. Bringing the entire pallet of components directly

into production would have resulted in excessive stockpiling on the line, creating a weekly buffer that would take up space unnecessarily, reducing the efficiency of the logistics system. To overcome this problem, a specific area within the warehouse was provided in which to transfer materials from the external packing units to those standardized for internal use, making the flow smoother and better manageable.
In the case of small parts, the subdivision of locations within the warehouse was made according to the machinery for which they are intended, ensuring a clear and accessible organization. This setup was designed to make the most of the available space. By doing so, we can keep the area from getting too crowded while still striking a balance between capacity and accessibility. Even though the layout doesn't allow us to display every single item we have, it's still effective enough to support most of our weekly production. This helps us prevent any interruptions that might come from running low on materials.
We've set up our shelving in a double-deep layout to really make the most of our storage space, all while keeping it easy to access what you need. This design lets us fit two boxes side by side in each section, which means there's always a backup supply of the materials you're currently using right at hand. As a result, it's simple for the operator to grab the components they need, and stock rotation happens naturally and smoothly. Thanks to this approach, we've seen a big boost in how efficiently we can procure materials, cutting down on waiting times and making the best use of the space we have in the production area.

Figure 5.1: New rack configuration for components at Ass.P6

Double-deep racking proves to be a strategic choice to ensure the continuity of production flow, avoiding the risk of lines running out of components and reducing the time spent by operators in searching for material within the department. In addition, the provision of a specific area for handling empty containers is a key point

for improving the monitoring of component utilization. This space makes it possible to check actual material consumption in real time, optimize timing planning for milk-run and classify components according to their frequency of use, distinguishing between those with high and low rotation. This not only ensures a steady and smooth flow of materials to the production line, but also results in more effective inventory management by improving the ability to monitor flows in and out of the warehouse and production. Compliance with FIFO logic and the elimination of waste thus become central elements in the procurement system, with an exclusive focus on value-added activities. In parallel with the optimization of the flow of materials, a method was developed to reorganize the layout of shelving within the supermarket, with the aim of making it more intuitive and efficient for line-servicing operations. This reorganization included the implementation of a clear and immediate identification system for each box and crate destined for the production line. As can be seen in the figure below, each container has been equipped with labels that uniquely state the part number and its specific destination. This system allows the operator to know in advance which box to pick and which code he will need for the shift.
The implementation of these identification labels proved to be particularly beneficial, as it simplified material picking and transport operations, speeding up the process and improving accuracy in parts handling. Thanks to this solution, the number of errors due to erroneous pickups, which in the past could lead to inefficiencies and slowdowns in the production cycle, has been significantly reduced. In addition, the adoption of a standardized system for box coding has helped smooth communication between the warehouse and the production line, ensuring greater consistency and reliability in internal logistics processes.

This new organization has also made it possible to increase the level of component traceability, providing a clearer and more detailed picture of consumption trends and actual production needs. In this way, it becomes possible to further refine supply planning, adapting the system to variations in demand and reducing situations of overstocking or material shortages. Optimization of internal logistics, supported by proper use of visual tools and more effective space management, is thus a significant step toward a leaner, more responsive and efficient production system.

Figure 5.2: Example of Components' Box for Ass.P6

Optimizing the management of components required a thorough analysis of the actual consumption of the small parts and boxes used between the supermarket and the production line. Although the wooden crates containing the small parts are not directly handled within the production area, but are stored in the main raw materials warehouse, it was essential to more carefully assess the number of items actually used per packing unit. In fact, while the initial check upon arrival of materials is done mainly on the basis of weight and rarely on numerical counting, it was necessary to develop a more accurate method for estimating the average weekly consumption of each component.
In particular, a system was defined to determine the average capacity of the internal packing units, sized according to the volume and footprint of the components. The small boxes dedicated to small parts were designed to hold an average of about 2,000 pieces, while larger boxes are used for larger items. Starting from this capacity, the number of pieces needed to produce a finished unit was calculated and then compared with the estimated weekly consumption. This comparison showed that some components are used with high frequency, while others experience much lower consumption.
This distinction allowed us to make the supermarket layout more efficient by giving us more room for high-demand items, which need to be restocked regularly throughout the day. For example, milk runs, where we swap out empty containers for full ones, are organized to keep materials flowing smoothly and prevent any delays in production. Conversely, for items that aren't consumed as quickly, we were able to decrease the allocated space. This freed up valuable resources for the more critical items.
The main goal of our study was to strike the right balance in inventory management. We developed a custom racking system designed to hold just the right amount of components needed for production. This analysis also became a essential tool for tracking actual consumption, leading to better procurement planning. With a clearer picture of what's actually being used, we could tweak our purchasing strategies, helping us avoid both overstocking and sudden shortages.
The approach we took resulted in two major benefits: we made better use of the available space and improved the efficiency of our material flow to the production line. This way, the company has built a more flexible and responsive system that can adjust dynamically to production needs and maintain a steady restock without waste or inefficiency.

5.3.1 Analysis of results

The implementation of the new racking system has thus had a significant impact on optimizing component handling time, significantly improving the overall efficiency of the production process. The reduction in material throughput time made possible an increase in weekly productivity, allowing smoother management of activities and greater responsiveness in meeting the needs of the P6 assembly line. One of the most notable aspects that emerged from the analysis was the drastic reduction in component search and retrieval activities, which previously involved a significant amount of time spent by line operators. Before the intervention, each operator had to move to the central warehouse, locate the platform containing the needed box, pick it up, and bring it back to his or her station, effectively interrupting the workflow for an average period of 10 minutes per shift. This process not only slowed down produc-

tion, but also generated increased operating costs without any added value for the company. With the introduction of racking positioned close to the production line, search and retrieval times have been reduced to less than a minute. The operator now has all the necessary totes directly on the machine, neatly arranged and easily identifiable through an intuitive visual system. This has eliminated more than 90 percent of unnecessary operations related to internal material handling, dramatically reducing the risk of unplanned interruptions in production.
From an economic point of view, the improved logistics organization has generated tangible savings. Considering that the cassette search and retrieval operation was carried out at least once a day for each operator, and taking into account a production cycle of five working days per week, it was estimated that the annual cost related to this inefficiency amounted to about €400.

In addition to the economic and production aspects, the new system also improved the working conditions of the operators, reducing their operational stress and optimizing the ergonomics of the workstations. Reduced need for unnecessary travel and greater efficiency in retrieving materials contribute to a more organized and functional work environment, reducing the risk of human error and improving the control of internal flows.

5.4 Analysis of the Previous State

This section will look in detail at the state prior to the implementation of the Thesis Project, with particular reference to the management of material supplies to the production lines by the forklift drivers, called Runners. The title of the chapter, Runner Project, originates precisely from this key figure, whose main task is the movement of materials within the plant and the constant replenishment of workstations and operating machines. The objective of this analysis is to understand and evaluate the previously adopted internal logistics flows, highlighting any critical issues and room for improvement in terms of efficiency, reliability and resource optimization.
The preliminary analysis starts with an assessment of the general organization of production within the Chivasso (TO) plant, considering the main dynamics governing the process of line and machine procurement. This process plays a key role in ensuring production continuity and regularity in finished product shipments. Materials management assumes strategic importance in a large plant, such as the one under consideration, as an ineffective logistics system can cause production disruptions resulting in delivery delays, increased operating costs and negative impacts on company competitiveness. In the automotive sector, which is characterized by high standards of efficiency and just-in-time manufacturing, the slightest mismatch in component supply can generate knock-on effects on the entire production line, with significant repercussions in terms of costs and timing. Within the Chivasso plant, the layout of the production and logistics areas is structured to ensure a constant and harmonious flow of materials between the various departments. The main areas involved in material management and handling can be divided into three main macro-categories.

- The first is the warehouses, which are used respectively for the storage of raw materials, the management of shipments, and the storage of packaging and packages for the finished product. These spaces, marked on the factory floor plan by the colors yellow, green and blue, are the starting and ending points of internal logistics flows.

- The second category concerns the production departments, which are divided into specialized sections according to the type of product made. Specifically, the main production departments are the HS department, which is dedicated to heat exchangers, the Unipiston department, which specializes in the processing of rubbers, and the Gasket and EMG department, which is intended for the production of dynamic gaskets. These departments, indicated in the floor plan with gray, light blue and violet colors, represent the beating heart of the plant and require constant and timely supply to ensure the smooth running of production activities.

- Finally, an area dedicated to production waste management is located on the outside of the plant. The latter is intended for the collection and disposal of waste resulting from industrial processing, in accordance with current environmental regulations and the company's sustainability policies.

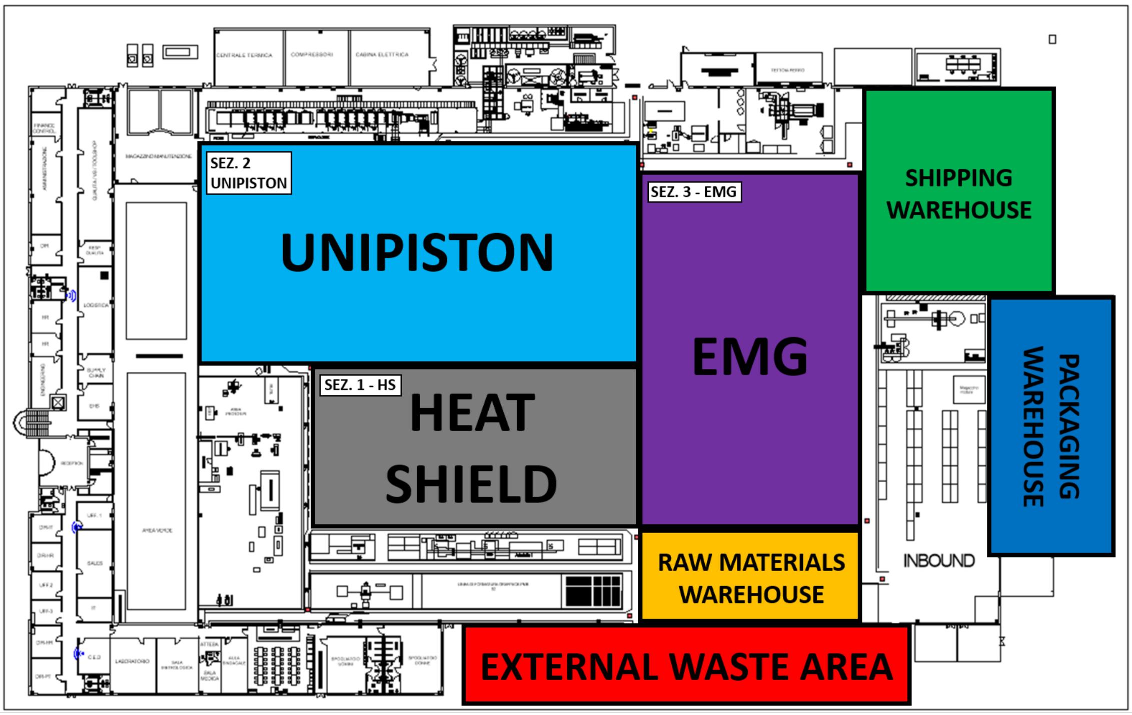


Figure 5.3: The Main Departments

The analysis of the previous state showed that the internal supply system was characterized by some inefficiencies mainly related to the dispersion of logistics flows, the lack of a clear system of material traceability, and the poor optimization of the routes followed by the forklift drivers. In particular, the absence of a structured method for line replenishment often led to situations of material overload in some areas and shortages in others, generating imbalances and delays in production operations. This problem was amplified by the complexity of the production environment, in which runners had to move between departments without a clear priority logic, increasing the risk of production interruptions and operational inefficiencies. The manual and non-standardized management of material requests was another critical factor, as it made real-time monitoring of production requirements difficult and increased the likelihood of human error in the distribution of components. This phenomenon, in addition to negatively affecting productivity, generated additional costs related to wasted materials and the high number of non-value-added movements. The lack of alignment between the warehouse and production also resulted in frequent emergency situations, where the sudden need for components led to interruptions and delays that were difficult to manage in the perspective of just-in-time production. The next chapter will examine the interventions proposed to optimize supply management, with a focus on redefining internal logistics flows, rationalizing inventories and implementing strategies aimed at reducing waste. Through the analysis of the adopted solutions and the results obtained, it will be possible to assess the impact of the Runner Project on the overall efficiency of the plant and the operational performance of production processes. During his work shift, the Runner, i.e., the operator in charge of managing the supply of materials to the production lines, performs a number of activities that are essential to the proper functioning of the entire plant. His role is not limited solely to the replenishment of machines and operating stations in the production departments, but also extends to the management of material flows between the raw materials, shipping and packaging warehouses, as well as including the transport and disposal of industrial waste in the appropriate outside area. This interconnection between the different areas makes the figure of the Runner crucial to the operational continuity of the entire production system, as failure to supply a component in a timely manner can lead to disruptions in the assembly line, generating high costs and operational inefficiencies.

Figure 5.4: External waste Area

During their 8-hour shift, the Runner's main job is to keep materials flowing smoothly and on time. It's all about making sure that machines and production lines don't stop because they're missing components. The goal is to deliver the right materials to each workstation exactly when they're needed, following a just-in-time system. This helps reduce waiting times and makes the best use of storage space along the line.

Thus, the **first** and most important task of the runner is to supply the production lines with the components needed for processing. As can be seen from the plant floor plan shown in the figure, numerous machines and assembly lines are in operation at the Chivasso production site, working simultaneously to ensure that daily production goals are met. Careful analysis and planning of procurement is therefore essential to ensure an optimal balance between material availability and production pace. Specifically, about twenty machines operate in the plant, each assigned to a specific location within the production departments.
In order for the entire system to operate efficiently and without interruption, the Runner must be able to manage the transport and placement of materials in a structured manner, following a predefined plan that takes into account the needs of each machine and the processing schedule. Parts are moved through predetermined routes that minimize unnecessary movement and reduce the risk of errors in line replenishment. Non-optimized management of these flows can generate significant delays and overload or material shortage situations, negatively affecting production performance and final product quality. In the following paragraphs, details regarding the management of supply flows will be explored, analyzing the internal handling logic adopted in the state prior to project implementation and assessing the critical issues encountered. The objective is to understand how runner activities were managed prior to the introduction of the proposed changes and what aspects affected the productivity and efficiency of the plant. Through this analysis it will be possible to identify areas for improvement and outline strategies adopted for optimizing the internal supply system.

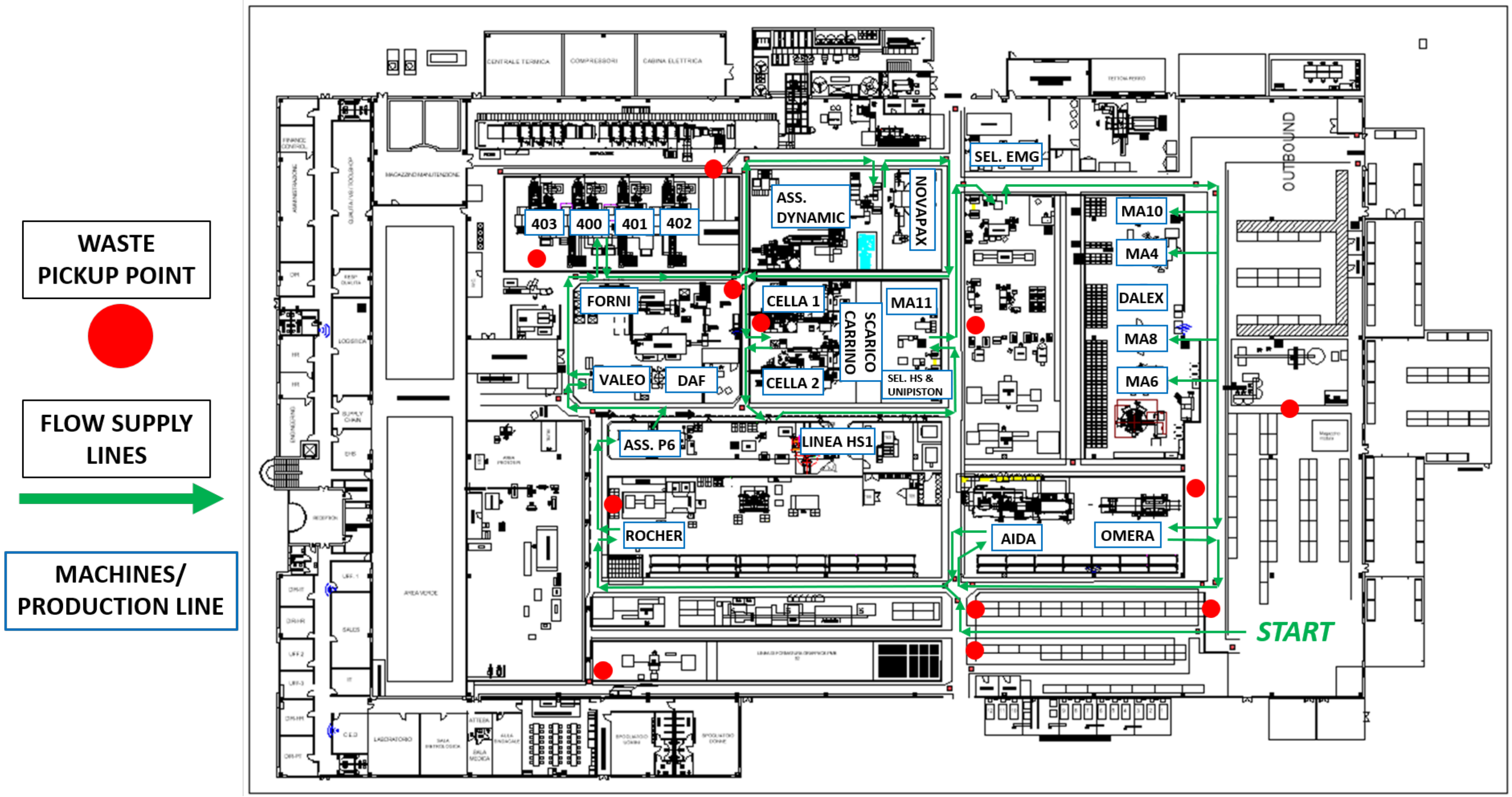


Figure 5.5: Production actual flows and Machines

The **second** aspect of fundamental importance in the operational management of the Runner concerns the proper disposal of waste and scrap from processing. Shown in the figure are the waste storage and pickup points, strategic areas for maintaining order and cleanliness within the plant. Production inevitably generates a significant amount of waste, resulting from non-conforming processing or components with quality defects, which must be removed promptly to avoid accumulation and subsequent inefficiencies in the production departments. For this reason, the Runner is in charge of constantly emptying the waste bins, transporting them to the appropriate collection areas and bringing back the empty containers. This operation, which must be carried out on a regular basis and coordinated with the rest of the logistics activities, is essential to ensure a safe and efficient working environment, reducing the risk of clutter that could hinder normal production flow.

The **third** crucial task of the Runner is the procurement of packaging and packaging materials for finished products. The entire production process, which originates from the raw materials warehouse and progresses through the various processing stages on the operating machines, culminates in a finished product ready to be shipped to the customer. For this process to be completed efficiently, it is essential that each machine is always supplied with the appropriate packaging materials, thus avoiding delays in the final stage of production. The Runner must therefore ensure that each production line has the correct packaging codes, which include boxes, containers, identification labels, and protective materials, needed to package products according to the customer's specific requirements.
Once the finished products are packaged, the Runner provides for their transfer to the storage pallets, which can be standard EUROPALLETs or special pallets provided directly by the customer. Proper management of this stage is critical to ensuring an efficient logistics flow, avoiding slowdowns in shipping operations. The packaged products are then transported to the dedicated shipping warehouse, where they are temporarily stored while awaiting the next stage of distribution. Typically, the holding period in the warehouse is relatively short, as shipments occur on a weekly basis, in line with the production plan and customer requirements.

Figure 5.6: Example of Packaging and Shipping Pallet

Optimizing these logistics activities has a direct impact on overall plant productivity. A well-organized Runner, capable of accurately managing material flows and coordinating line replenishment with production needs, contributes significantly to reducing waste and improving operational efficiency. The next chapter will analyze in detail the average execution time of these operations and the critical issues found in the previous state, with the aim of identifying areas for improvement and solutions implemented to optimize the internal logistics system.

5.4.1 Analysis of supply flows in production areas

The analysis of supply flows in the production areas revealed numerous critical issues in the management of raw material handling, packaging, and finished product pallets. This study, conducted over five months at the Tenneco plant in Chivasso (TO), identified significant inefficiencies in internal logistics and proposed targeted solutions to optimize production flows.
Through a four-week observation period, conducted with the help of measurement tools such as stopwatch and GPS tracking, detailed data were collected on the routes followed by the runner and the time spent on various logistics activities. The analysis immediately revealed a non-standardized management of supply flows: the Runner did not follow a logical and predetermined sequence in supplying the production lines, but operated solely on the basis of extemporaneous requests from line operators. The latter, lacking clear planning, found themselves having to call the Runner via cell phone or by voice at the very moment when the material on the machine ran out. This management mode led to serious inefficiencies, resulting in delays, downtime and additional costs for the company.
One of the most significant problems that emerged during the analysis was the absence of a structured plan for material handling within the production area. Each day the runner followed different routes, determined solely by the urgencies reported by the operators. This lack of standardization meant not only a waste of time and resources, but also the risk of overloading the Runner at certain times of the day. In fact, in the event that several operators requested supplies at the same time, the Runner was forced to manage priorities according to urgency, resulting in some machines temporarily running out of needed material, causing disruptions in production. This problem was particularly critical in the automotive context, where adherence to production and delivery schedules is essential to ensure supply chain continuity.
During the four-week study, it was possible to accurately map the daily activities performed by the Runner, highlighting the distribution of working time among different logistics operations. It was found that the Runner took an average of 2.5 hours for each complete replenishment cycle, including raw material pickup, delivery to the machine, waste management, and transfer of finished goods pallets to the shipping warehouse. This cycle was repeated three times per shift, covering the entire 8-hour workday. However, the absence of a structured flow and the unpredictability of demands made these times highly variable, causing congestion and moments of unproductive downtime.
For a more in-depth understanding of the inefficiencies, the table below details the Runner's individual movements. The table shows the sequence of daily activities, distinguishing between loaded and unloaded movements, the starting and destination point of each movement, the type of material transported, the time and distance

traveled for each operation, and the vehicle used (forklift or electric stacker). The analysis of this data enabled the identification of the main critical points and opportunities for improvement, which will be discussed in more detail in the next chapter.

This phase of the study was key to understanding the reason for the inefficiencies found and to identify the areas of intervention needed to improve internal logistics management. The following chapters will present the strategies adopted to optimize supply flows, with a focus on introducing a standardized system to reduce waiting times, improve materials management, and ensure a smoother and more efficient production flow.

SEQUENCE	FULL/EMPTY	SUPPLIER	CUSTOMER	MATERIALS	TIME (s)	DISTANCE (m)	MEANS OF TRANSPORT
1	F	Magazzino MP	Omera + Aida + Rocher	3 coil	540	390	Muletto
2	F	Dep rifiuti R/L	Rifiuti esterni	Sfridi pieno x3	720	690	Muletto
3	F	Rifiuti esterni	Dep rifiuti R/L	Sfridi vuoto x3	180	690	Muletto
4	E	Dep rifiuti R/L	Dep rifiuti Omera	Vuoto	30	100	Muletto
5	F	Dep rifiuti Omera	Rifiuti esterni	Sfridi pieno x3	360	360	Muletto
6	F	Rifiuti esterni	Dep rifiuti Omera	Sfridi vuoto x3	90	360	Muletto
7	E	Dep rifiuti Omera	Picking pack	Vuoto	30	30	Muletto
8	F	Picking pack	P6 + Linea HS + Selezione	Pedana pack x3	360	570	Stoc elet
9	F	P6 + Linea HS + Selezione	Mag PF	Pedana finita x3	540	480	Stoc elet
10	E	Magazzino PF	MA10	Vuoto	10	15	Stoc elet
11	F	MA10 + MA4 + MA8	Mag PF	Pedana finita x3	180	60	Stoc elet
12	E	Magazzino PF	Picking pack	Vuoto	20	60	Stoc elet
13	F	Picking pack	MA8 + MA4 + MA10	Pedana pack x3	180	150	Stoc elet
14	E	MA10	Dep rifiuti Unipiston	Vuoto	30	70	Muletto
15	F	Dep rifiuti Unipiston	Cella 2	Rifiuti vuoto	20	40	Stoc elet
16	F	Cella 2	Dep rifiuti Unipiston	Rifiuti pieno	20	40	Stoc elet
17	E	Dep rifiuti Unipiston	Metalli fosfatati	Vuoto	30	30	Stoc elet
18	F	Metalli fosfatati	P400 + P403	Metalli fosfatati x2	40	40	Stoc elet
19	F	P403	Forno	Carrino pieno	30	10	Stoc elet
20	F	Forno	Deposito carrini	Carrino pieno	60	30	Stoc elet
21	F	Deposito carrini	P403	Carrino vuoto	30	30	Stoc elet
22	E	P403	P400	Vuoto	10	10	Stoc elet
23	F	P400	Forno	Carrino pieno	30	10	Stoc elet
24	F	Forno	Deposito carrini	Carrino pieno	60	30	Stoc elet
25	F	Deposito carrini	P400	Carrino vuoto	30	30	Stoc elet
26	E	P400	Metalli fosfatati	Vuoto	20	20	Stoc elet
27	F	Metalli fosfatati	Cella 2	Metalli fosfatati	20	30	Stoc elet
28	F	Cella 2	Forno	Carrino pieno	30	30	Stoc elet
29	E	Forno	Deposito carrini	Vuoto	30	40	Stoc elet
30	F	Deposito carrini	Cella 2	Carrino vuoto	30	20	Stoc elet
31	E	Cella 2	Dep rifiuti Unipiston	Vuoto	30	20	Stoc elet
32	F	Dep rifiuti Unipiston	P400 + P403	Rifiuti vuoto x2	60	40	Muletto
33	F	P403	Dep rifiuti Unipiston	Rifiuti pieno x3	90	60	Muletto
34	F	Dep rifiuti Unipiston	Rifiuti esterni	Rifiuti pieno x3	720	900	Muletto
35	F	Rifiuti esterni	Dep rifiuti Unipiston	Rifiuti vuoto x3	180	900	Muletto
36	E	Dep rifiuti Unipiston	Dep rifiuti scaff MP	Vuoto	60	50	Muletto
37	F	Dep rifiuti scaff MP	Rifiuti esterni	Rifiuti pieno x3	540	540	Muletto
38	F	Rifiuti esterni	Dep rifiuti scaff MP	Rifiuti vuoto x3	180	540	Muletto
39	F	Dep rifiuti scaff MP	Rifiuti esterni	Rifiuti pieno x2	480	360	Muletto
40	F	Rifiuti esterni	Dep rifiuti scaff MP	Rifiuti vuoto x2	120	360	Muletto
41	E	Dep rifiuti scaff MP	Dep rifiuti Omera	Vuoto	60	30	Muletto
42	F	Dep rifiuti Omera	Rifiuti esterni	Sfridi pieno x3	540	360	Muletto
43	F	Rifiuti esterni	Dep rifiuti Omera	Sfridi vuoto x3	180	360	Muletto
44	E	Dep rifiuti Omera	Dep rifiuti R/L	Vuoto	60	100	Muletto
45	F	Dep rifiuti R/L	Rifiuti esterni	Sfridi pieno x3	720	690	Muletto
46	F	Rifiuti esterni	Dep rifiuti R/L	Sfridi vuoto x3	180	690	Muletto
47	E	Dep rifiuti R/L	Picking pack	Vuoto	60	130	Muletto
48	F	Picking pack	Linea HS	Pedana pack	30	190	Muletto
49	F	Linea HS	Mag PF	Pedana finita	30	160	Muletto

Figure 5.7: Analysis of Current supply flows

The combined use of both tools, the electric stacker and the forklift, allowed the Runner to adapt to the different logistical needs of the plant, optimizing procurement and internal handling times. The choice between the two tools depended not only on the type of load to be transported, but also on the configuration of spaces within the production area and the need to ensure a continuous and efficient workflow.
During the work shift, the Runner primarily used the electric stacker to move and position pallets that held raw materials, packaging, or finished products around the production areas. Thanks to its compact design and agile movements, the stacker made it easy to operate in the tight aisles between production lines, helping

to minimize the chances of collisions and making sure that line operators could continue their work without any interruptions. In contrast, the forklift was employed for tasks that needed more lifting power and the ability to transport items over longer distances. A typical example was the transfer of pallets containing finished product from the production floor to the shipping warehouse, an operation that often involved transporting heavy and bulky loads. In addition, due to its robustness and increased operating speed, the forklift was more efficient for picking up large quantities of raw materials from warehouses and then distributing them to different production departments. However, precisely because of its larger size and wider turning radius, the forklift required more attention when maneuvering and was not always the ideal solution for handling within the most congested production areas.

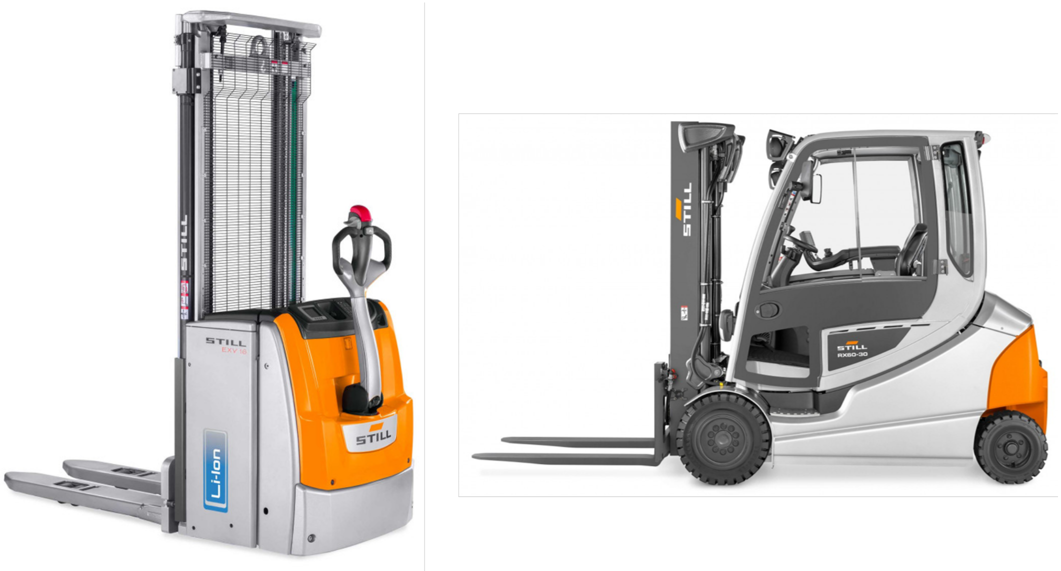


Figure 5.8: Electric stacker and forklift

A critical issue that emerged during the logistics flow analysis concerned the actual availability and optimal use of the two vehicles. Although the Runner had the ability to alternate the use of the stacker and forklift according to operational needs, it was observed that often the choices of use were dictated more by personal preference than by a logic of operational efficiency. Specifically, in some situations, it was noted that using the forklift for operations that could have been performed with the stacker resulted in more difficult maneuvering and longer lead times, while in other cases, using the stacker for loads above its rated capacity resulted in slowdowns and the need to break down operations into multiple steps, resulting in wasted time. For this reason, one of the key phases of the Thesis project involved analyzing the optimal use of the two handling means and establishing guidelines for their more rational and efficient use. The goal was to reduce wasted time associated with suboptimal choices, improve safety in transportation operations, and ensure smoother internal logistics flow.
In the following chapters, the proposed solutions for optimizing forklift and stacker use will be explored, with a focus on defining standardized routes, planning runner activities, and implementing strategies for reducing inefficiencies in the production line supply system.

5.4.2 Conclusions and reflections

As a result of the analyses conducted on the current state of the management of internal material handling flows and platforms, the importance of redesigning these flows to improve efficiency and productivity became clear. The Thesis project focused on this very aspect, attempting to solve the issues related to material handling, finished goods pallets, and production line supply. As we saw earlier, the current system had significant inefficiencies: the runner's work was not standardized, and tasks were performed in a haphazard manner, with no precise flow to follow. This caused continuous delays, downtime, and chaotic resource management, resulting in wasted time and money.

Therefore, the primary goal of the project was to bring order and rationality to the Runner's work by introducing a system of standardized procurement flows. The proposal was to adopt the Milkrun system, which provides for regular and continuous replenishment of production lines, avoiding random calls and reducing waits. With Milkrun, materials are brought to the lines in a planned manner, eliminating spikes in sudden demand and optimizing routes, preventing the runner from moving around unnecessarily or making excessively long turns.

In addition, a new route organization has been designed for the Runner, who can now follow a logical flow, avoiding confusion. Each material has a fixed destination within the plant, and replenishment routes have become repetitive and faster. This has also resulted in improved waste management: before, the operation of emptying waste bins was carried out in a disorganized manner, while now a clear schedule has been established to ensure their proper disposal without creating clutter in the production area.

The benefits of this new organization have been obvious. Line supply time has been reduced, downtime has decreased, and runner routes have been optimized, saving considerable time. Standardization has made the workload during the shift more balanced, improving the overall efficiency of the plant. As a result, work not only became smoother, but also much safer and more organized, with a positive impact on costs and overall productivity.

5.5 Redesign of Internal Flows

In this section of the Thesis Project, the analysis and development process of the Runner Project, aimed at reorganizing and optimizing internal material handling flows within the plant, will be detailed. The primary objective of this project was to significantly reduce the delivery time of materials to the workstations and to improve the entire procurement process of the production lines. In particular, the focus was on optimizing the management of raw material, packaging material for the packaging of finished products, and the KLT pallets and totes used to transport goods from the production department to the shipping warehouse.

As analyzed in the previous chapter, the internal handling system had significant inefficiencies due to the lack of standardization of routes and replenishment logics adopted by the Runner, which transported materials and components only upon direct request by line operators, without following a predefined flow. This resulted in wasted time, redundant routes and a general disorganization of work that compromised a smooth replenishment of materials to the workstations. The lack of a structured supply system led, in the most critical cases, to delays in the delivery

of raw materials and even downtime, negatively impacting productivity and overall plant efficiency.
The analysis of internal logistics flows revealed the need for an intervention aimed at improving the Runner's activities, through the introduction of a more efficient replenishment strategy, capable of eliminating activities with no added value and ensuring a harmonious and coordinated flow of internal handling. The main objective of the redesign was to minimize downtime and optimize routes, ensuring a constant supply of production lines. To achieve this, it was necessary to develop a new operating model based on standardization and replenishment scheduling logics, introducing the concept of Milk-run, i.e., a cyclic delivery system that allows materials to be distributed in a regular and uniform manner, reducing urgent and unforeseen demands as much as possible.

The implementation of this new approach has enabled better definition of replenishment routes, and optimizing the sequence of operations performed by the Runner.

5.5.1 Inter-Company Milk-Run

As described in the previous section, one of the main critical issues that emerged in the analysis of internal material handling flows within the production area concerns the lack of standardization in the operations and routes followed for production procurement and related ancillary activities. Through a direct study conducted in the field over a four-week period, with the help of a stopwatch, it was possible to quantify the average time required to complete a single handling cycle, which was around 2.5 hours. This interval encompassed all the activities performed by the Runner, including replenishing the lines with the necessary raw materials, moving boxes and packaging pallets, transferring finished products to the shipping warehouse, emptying waste bins in the dedicated areas, and moving pallets containing semi-processed products (Work in Progress, WIP) between the various departments in the plant.
Detailed analysis of the timing and distances travelled by the Runner revealed the need for action to improve the efficiency of internal flow management. In this context, it was deemed appropriate to introduce an inter-company milk-run system. The adoption of this system represents a strategic solution to drastically reduce the time and distances travelled in the internal handling of milk-runs, optimizing the transport of materials to the production lines and improving the balance of operational activities.
The intercompany milk-run involves the introduction of a new internal transport system, which would partially replace the current handling done with forklifts and electric stackers. Specifically, the system would be based on the use of a logistic train, consisting of an operator-driven main unit (called a 'matrix') to which several modular wagons are attached, connected by a system of hooks that can be easily assembled and disassembled. The configuration of the logistic train can vary according to production needs, allowing different types of materials to be transported simultaneously in a single replenishment cycle.

The use of the logistics train would enable the implementation of a cyclic and scheduled replenishment flow, eliminating inefficiencies related to improvised demands and irregular routes followed by the Runner in the previous system. In addition, with the ability to transport materials for several workstations simultaneously, there would be a significant reduction in the number of trips required to complete a replenishment cycle, resulting in improved operational efficiency and reduced costs associated with internal handling. The following paragraphs will detail the steps involved in implementing the inter-company milk-run, analyzing the benefits obtained and comparing the performance of the new system with that of the traditional method of handling.

Figure 5.9: Inter-company Milk-Run Train [19]

As the figure shows, the inter-company milk-run system relies on the use of a tractor, often represented by a forklift or electric stacker. In addition to performing their primary function-that is, lifting and transporting heavy loads, warehouse allocation of finished goods pallets, unloading of waste bins, and other logistical operations-these vehicles can also haul materials. Thanks to a special coupling system, the tractor unit is able to haul a series of wagons designed to transport different types of materials, including packaging boxes and pallets for finished products, components intended for production, and semi-finished products (Work in Progress, WIP) from one department to another in the plant.
This solution allows all internal handling activities to be integrated into one continuous flow, contributing to harmonious and coordinated management of the entire production process. The use of modular wagons provides considerable operational flexibility: they can be easily attached or detached according to production needs, allowing the transportation system to be quickly adapted to changes in demand or any critical operational issues. In addition, the wagons are designed to accommodate a wide range of different sized containers and platforms, thus providing high versatility in transporting materials.

Check out the diagram below. It shows how the wagon setup can transport various types of cargo at the same time. This means we can make fewer trips to restock our lines and cut down on handling time. Not only does this boost our logistics efficiency, but it also makes life easier for the operators. With less manual lifting involved, we can improve safety and make everyone's job a bit better.

Figure 5.10: Example of Tow Train for Milk-Run

After a thorough feasibility analysis and a series of meetings with production and company managers, the project was officially initiated and implemented within the plant. The first step was the design of a dedicated area, called the milk-run kitting area, specifically set up to allow the Runner to prepare the little train and related wagons with the materials needed to supply the production lines.
Since it is impossible to supply the entire production in a single run, the milk-run system was designed to operate through multiple runs distributed throughout the Runner's eight-hour shift. The frequency of replenishment was designed to respond to production needs by prioritizing the departments or machines with the greatest urgency for supply. In this way, machine downtime due to lack of materials was avoided, significantly improving the smoothness of the production process.
Take a look at the chart below. You'll see that the kitting milk-run area was cleverly placed right near the entrance of both the FIFO raw material warehouse and the packaging warehouse. This choice turned out to be pretty beneficial because it puts the runner in a sweet spot between the two warehouses. As a result, it cuts down on travel time for picking and loading pallets and materials onto the vehicles. This setup has led to a nice drop in the total distances traveled during our internal handling operations.

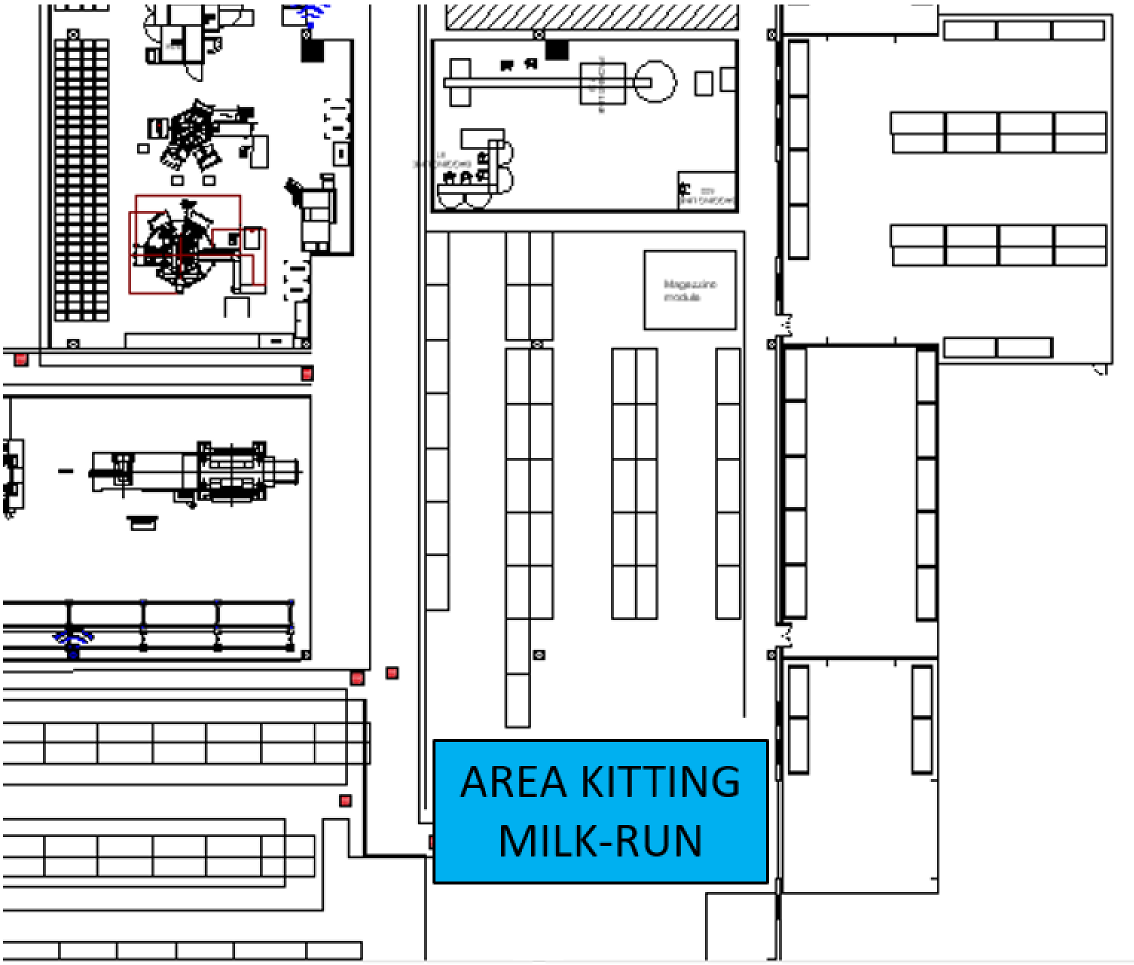


Figure 5.11: Area Kitting for Milk-Run

At the beginning of the shift, the Runner is now responsible for setting up his or her own train and loading the cars with the materials needed to replenish the lines. This approach has eliminated the inefficiencies associated with the previous mode of operation, in which the Runner had to perform each operation individually, using only one means of transport at a time, such as a forklift or electric stocker. Thanks to the introduction of the engine with coupled wagons, it is now possible to move significantly more pallets, KLT totes, bins, raw materials, packaging, and packaging at the same time, drastically reducing the number of trips required to complete supply operations. This has avoided the many empty trips present with the old configuration. In the past, each time the Runner finished a delivery, he was forced to return to the warehouse to pick up the material destined for the next line, repeating this process for each and every replenishment. This operating model generated an extremely high expenditure of time and resources and ended up being an inefficient cycle that penalized the entire production flow and related activities,. With the new system, however, the organization of activities has been optimized according to more structured logic, reducing downtime and improving the sequentially of operations. The ability to load multiple materials destined for different production lines in a single run has made the process more efficient, reducing both supply times and the distances travelled by the Runner within the plant.

The results obtained were extraordinary: there was an increase in operational efficiency of up to 60%.

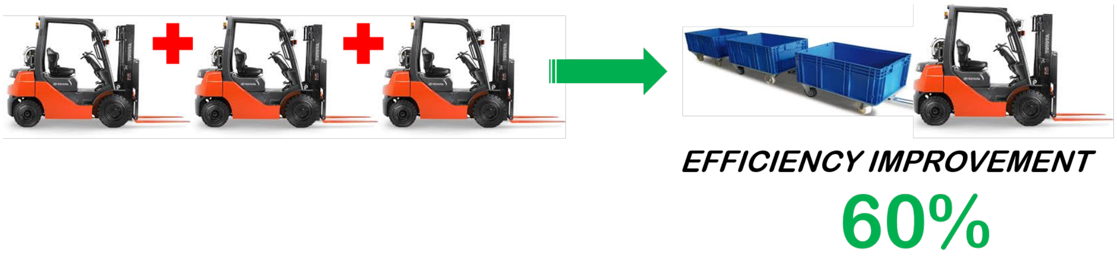


Figure 5.12: Scheme of Improvement of efficiency

5.5.2 Flow and frequency analysis

During the four-week observation period, each machine and production line was monitored individually to understand the specific replenishment and handling needs. Using the double-entry table made on excel, it was possible to correlate the different operational activities with the machines involved in the production process. On the rows were listed all the machines and lines present in the plant, while on the columns were classified the main operations performed by the Runner, including replenishment of raw materials, moving pallets, transporting materials for packaging, waste management, and other auxiliary activities.
This structured representation made it possible to clearly visualize the number and type of operations required for each machine. In addition, through a colour analysis of the data, it was possible to immediately identify the areas of greatest concentration of activities, highlighting the most impactful processes in terms of time and resources used.

The next section will analyze in detail the optimized path developed as a result of this analysis, with an in-depth description of the changes implemented to improve operational efficiency and ensure a harmonious and continuous flow of handling activities within the plant.

Figure 5.13: Machines and Production lines flows

Graphical analysis of the data made it possible to accurately identify the activities that required the most of the Runner's operational time, thus highlighting the areas where action could be taken to achieve significant efficiency improvements. It is clearly visible from the table that the most frequent activities in the Runner's work shift are picking up and transporting pallets with finished goods to the shipping warehouse and moving empty KLT totes between the various machines and production lines.
This data allowed us to understand where to intervene to reduce handling times and improve the sequence of operations. In particular, transporting the pallets with finished products to the shipping warehouse turned out to be a particularly time- and resource-consuming operation, as the Runner often had to travel long distances several times during the shift. This waste of time and energy generated a negative impact on the productivity of the entire plant, increasing material handling times and reducing the Runner's availability for his other activities.
Internal handling of the KLT blue boxes was also not taking place according to a clear and pre-established criterion thus causing high variability and increasing the number of unnecessary trips also leading to production and organizational inefficiencies.

Starting from here, it was therefore possible to study a plan to improve the situation by thinking about the standardization of activities and the reorganization of handling routes. The following paragraphs will analyze in detail the solutions implemented to reduce the number of empty trips, optimize the transport of empty pallets and KLTs, and ensure greater overall efficiency in the flow of materials within the production plant.

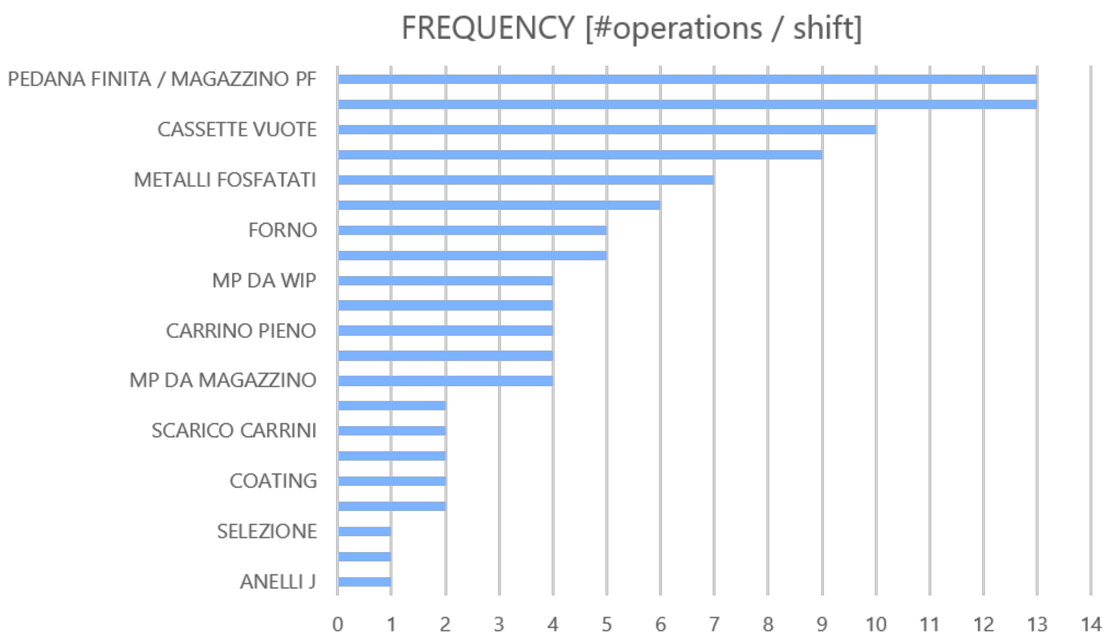


Figure 5.14: Operations and activities frequency

At this point in the analysis, it was important to delve deeper into the issue of internal material handling management in order to identify a solution that would optimize processes and improve operational efficiency. Specifically, the activities performed by the Runner during the work shift were particularly time-consuming, as they did not follow a standardized logic and were not structured according to optimized flows. The absence of a well-defined route and effective organization of replenishment operations generated numerous inefficiencies, resulting in wasted time and an increased number of unnecessary trips. To solve these critical issues, it was necessary to make a thorough study of internal logistics flows, aimed at reducing travel time and increasing the overall productivity of the system.
The analysis was conducted by collecting data on the flows and frequencies of platform and material handling within the plant. For this, a double-entry table was made on Excel, in which all movements made by the runners during their eight-hour shift were recorded and classified. The study was carried out over a period of four weeks, during which the routes taken, the times each task was performed and the distances travelled were monitored in detail.
As shown in the table, each activity was organized in sequence to ensure orderly and standardized supply to the production lines. The definition of this sequence was the result of direct discussion with the production manager and department managers in order to meet the priorities and production needs established on a daily basis. The structure of the table developed is similar to that developed to represent the pre-existing situation, that is, before the implementation of the new handling system. However, what significantly emerges from the comparison of the two states is the improvement in terms of operational efficiency.
From the detailed analysis of the execution time of each operation and the distances travelled, it was possible to quantify a significant increase in the overall efficiency of the system, which can be attributed to the introduction of Milk-Run as a method of material and platform handling. As a result of this solution, there has been a drastic reduction in the time required to replenish production lines, as well as in the distances travelled to complete logistics activities. In particular, this system has eliminated many unnecessary trips, which previously represented a significant cost for the company without adding value to production.

Another crucial aspect that emerged from the analysis concerns the type of transportation means used for internal material handling. Indeed, in the table, the last column shows the means used for each activity. There are mainly three options available:

1. Milk-Run represents the most efficient system in most operations, since it allows multiple loads to be transported simultaneously, thus reducing the number of trips and optimizing the flow of materials. This method involves the use of a tractor-which can be a forklift or an electric stacker-to which one or more wagons are attached, depending on the daily production demand. The adoption of this system has made it possible to minimize the number of empty trips and significantly reduce the costs associated with internal logistics;

2. However, there are situations in which the use of Milk-Run is not the most suitable choice. With smaller replenishment orders, the use of the multi-car train may be inefficient and even counterproductive. In such circumstances, it is preferable to adopt an electric stacker or forklift, so as to ensure a more agile supply targeted to actual operational needs. An additional factor to consider relates to the spatial limitations present within the plant: in some areas, the bending radii required to maneuver the small train exceed the spaces physically available in the aisles and work areas. In these cases, the use of an articulated conveyor system would be excessively cumbersome and potentially hazardous to operator safety.

So, the optimization of logistics flows has resulted in a significant increase in operational efficiency, achieved through in-depth analysis of handling data and the consequent implementation of a more rational and flexible transportation system. The adoption of Milk-Run has made it possible to drastically reduce the number of trips required to replenish lines, while improving safety and overall work organization. In the next sections, the results obtained from the process optimization will be analyzed in detail through a comparison of the previous system and the currently implemented system.

SEQUENCE	FULL/EMPTY	SUPPLIER	CUSTOMER	MATERIALS	TIME (s)	DISTANCE (m)	MEANS OF TRANSPORT
1	F	Magazzino MP	Omera + Aida + Rocher	3 coil	180	130	Milkrun
2	F	Dep rifiuti R/L	Rifiuti esterni	Sfridi pieno x3	240	230	Milkrun
3	F	Rifiuti esterni	Dep rifiuti R/L	Sfridi vuoto x3	60	230	Milkrun
4	E	Dep rifiuti R/L	Dep rifiuti Omera	Vuoto	30	100	Motrice milkrun
5	F	Dep rifiuti Omera	Rifiuti esterni	Sfridi pieno x3	120	120	Milkrun
6	F	Rifiuti esterni	Dep rifiuti Omera	Sfridi vuoto x3	30	120	Milkrun
7	E	Dep rifiuti Omera	Picking pack	Vuoto	30	30	Motrice milkrun
8	F	Picking pack	P6 + Linea HS + Selezione	Pedana pack x3	120	190	Milkrun
9	F	P6 + Linea HS + Selezione	Mag PF	Pedana finita x3	180	160	Milkrun
10	E	Magazzino PF	MA10	Vuoto	10	15	Motrice milkrun
11	F	MA10 + MA4 + MA8	Mag PF	Pedana finita x3	60	20	Milkrun
12	E	Magazzino PF	Picking pack	Vuoto	20	60	Motrice milkrun
13	F	Picking pack	MA8 + MA4 + MA10	Pedana pack x3	60	50	Milkrun
14	E	MA10	Dep rifiuti Unipiston	Vuoto	30	70	Motrice milkrun
15	F	Dep rifiuti Unipiston	Cella 2	Rifiuti vuoto	20	40	Stoc elet
16	F	Cella 2	Dep rifiuti Unipiston	Rifiuti pieno	20	40	Stoc elet
17	E	Dep rifiuti Unipiston	Metalli fosfatati	Vuoto	30	30	Stoc elet
18	F	Metalli fosfatati	P400 + P403	Metalli fosfatati x2	20	20	Stoc elet
19	F	P403	Forno	Carrino pieno	30	10	Stoc elet
20	F	Forno	Deposito carrini	Carrino pieno	60	30	Stoc elet
21	F	Deposito carrini	P403	Carrino vuoto	30	30	Stoc elet
22	E	P403	P400	Vuoto	10	10	Stoc elet
23	F	P400	Forno	Carrino pieno	30	10	Stoc elet
24	F	Forno	Deposito carrini	Carrino pieno	60	30	Stoc elet
25	F	Deposito carrini	P400	Carrino vuoto	30	30	Stoc elet
26	E	P400	Metalli fosfatati	Vuoto	20	20	Stoc elet
27	F	Metalli fosfatati	Cella 2	Metalli fosfatati	20	30	Stoc elet
28	F	Cella 2	Forno	Carrino pieno	30	30	Stoc elet
29	E	Forno	Deposito carrini	Vuoto	30	40	Stoc elet
30	F	Deposito carrini	Cella 2	Carrino vuoto	30	20	Stoc elet
31	E	Cella 2	Dep rifiuti Unipiston	Vuoto	30	20	Stoc elet
32	F	Dep rifiuti Unipiston	P400 + P403	Rifiuti vuoto x2	30	20	Milkrun
33	F	P403	Dep rifiuti Unipiston	Rifiuti pieno x3	30	20	Milkrun
34	F	Dep rifiuti Unipiston	Rifiuti esterni	Rifiuti pieno x3	240	300	Milkrun
35	F	Rifiuti esterni	Dep rifiuti Unipiston	Rifiuti vuoto x3	60	300	Milkrun
36	E	Dep rifiuti Unipiston	Dep rifiuti scaff MP	Vuoto	60	50	Motrice milkrun
37	F	Dep rifiuti scaff MP	Rifiuti esterni	Rifiuti pieno x3	180	180	Milkrun
38	F	Rifiuti esterni	Dep rifiuti scaff MP	Rifiuti vuoto x3	60	180	Milkrun
39	F	Dep rifiuti scaff MP	Rifiuti esterni	Rifiuti pieno x2	240	180	Milkrun
40	F	Rifiuti esterni	Dep rifiuti scaff MP	Rifiuti vuoto x2	60	180	Milkrun
41	E	Dep rifiuti scaff MP	Dep rifiuti Omera	Vuoto	60	30	Motrice milkrun
42	F	Dep rifiuti Omera	Rifiuti esterni	Sfridi pieno x3	180	120	Milkrun
43	F	Rifiuti esterni	Dep rifiuti Omera	Sfridi vuoto x3	60	120	Milkrun
44	E	Dep rifiuti Omera	Dep rifiuti R/L	Vuoto	60	100	Motrice milkrun
45	F	Dep rifiuti R/L	Rifiuti esterni	Sfridi pieno x3	240	230	Milkrun
46	F	Rifiuti esterni	Dep rifiuti R/L	Sfridi vuoto x3	60	230	Milkrun
47	E	Dep rifiuti R/L	Picking pack	Vuoto	60	130	Motrice milkrun
48	F	Picking pack	Linea HS	Pedana pack	30	190	Milkrun
49	F	Linea HS	Mag PF	Pedana finita	30	160	Milkrun

Figure 5.15: Analysis of Future State of supply flows

The results show that prior to the implementation of the new handling system, the Runner took an average of about 2.5 hours to complete an entire round trip to refuel the machines. Thanks to the newly implemented solution, which is based on the use of a tractor with wagons pulled by special hooks, there has been a drastic reduction in both travel time and the distances travelled by the handling equipment. One of the most significant aspects of the optimization concerns the elimination, or at least the drastic reduction, of empty trips, i.e., non-productive trips that were a source of waste in terms of both time and operating costs. In the previous configuration, in fact, forklifts and electric stackers frequently had to return empty to the starting point, such as the raw materials warehouse, before new material destined for the production machines could be picked up. Milk-Run, already described in the previous section, played a key role in this improvement, allowing more materials to be transported simultaneously and reducing the number of trips required to complete line replenishment. This had a significant impact on overall productivity, as it allowed the Runner to focus solely on essential tasks, avoiding unnecessary trips and improving time management within the work shift.

5.5.3 Operating Instructions and New Runner Scheduling

As a result of the analyses conducted and studies carried out regarding the optimization of internal logistics flows for the movement of materials and platforms within the production area, an additional project was developed with the aim of providing Runners with a clear and structured guideline in order to improve their respective activities. The project was created to ensure greater operational efficiency by reducing unproductive time and minimizing errors resulting from unclear and intuitable work instructions. Therefore, a method was devised that would enable the Runners to perform their daily activities in an optimized manner, with a focus on reducing travel time for picking up and replenishing materials to the production lines, and eliminating inefficiencies caused by equivocal communication. To achieve this goal, detailed operating instructions have been introduced that each Runner is required to follow in detail. These instructions were made to ensure an orderly workflow, avoiding delays and misunderstandings and enabling more effective management of activities. The adoption of this scheduling system that we are going to look at below has allowed the work of the Runners to be structured more clearly and efficiently, through a strict organization of activities and a precise division of responsibilities. The implemented scheduling system provides for the division of activities by departments and further by specific machines.
In particular, we will now go on to look at the structure and operation of the runner scheduling system that was proposed during this thesis project. The work scheduling system for runners within the plant is organized to ensure an efficient and standardized workflow. Tasks are divided by departments and further subdivided according to specific machines.

In particular, the "On the Job" column is divided into two sections, "Current Shift" and "Next Shift," and their compilation follows a specific order of responsibility:

- **Current shift**: this section must be filled in by the team leader of the shift preceding the one in question or, if the team leader is unable to do so, by the runner himself at the beginning of his shift. In this case it must be indicated which machines will be working during the shift in question;
- **Next shift**: filling in this column is the responsibility of the team leader of the shift in question towards the end of the shift. This allows the runner to prepare the machines for the start of the next shift, ensuring that work can begin without delay or urgency.

Each shift must complete its own worksheet, which means that three separate sheets (one for each runner) must be completed over the course of a workday. To maintain standardization of work, it is essential to follow the order of operations cyclically, stopping at the indicated machines only when necessary. The order of operations should be interrupted in case of an urgent call and then resumed regularly once it is resolved. The scheduling system has been implemented with the following objectives:

- Standardization: ensuring that all tasks are carried out according to uniform procedures so that every operator performs tasks in the same way;
- Workload balancing: levelling the workload among the three shifts to avoid excessive imbalances;
- Reducing urgent calls: minimizing urgent requests from operators so that they are needed only in case of unexpected changes in the production schedule;
- Workload monitoring: to better understand the workload of each shift, it is essential to note on the back of the sheet the approximate number of hours taken to perform all planned activities, as well as any additional activities performed in addition to those already present.

Data:			Turno:	Runner:	
Reparto	Numero fermata	Macchina	Attività	In lavoro	
				Turno in corso	Turno successivo
Unipiston +HS	1	Rocher	Portare coil a bordo macchina		
	2	Assemblaggio P6	Portare componenti per assemblaggio		
	3	Coating	Portare carrino pieno e anelli J		
	4	Valeo	Portare carrino pieno		
	5	Pressa 403	Portare metalli fosfatati e carrino vuoto + mettere carrino pieno in forno		
		Pressa 400	Portare metalli fosfatati e carrino vuoto + mettere carrino pieno in forno		
		Pressa 401	Portare metalli fosfatati		
		Pressa 402	Portare metalli fosfatati e carrino vuoto + prelevare carrino pieno		
		Forni	Tirare fuori dal forno carrino pieno		
	6	Rettifica	Portare carrino pieno, corone e pedana		
	7	Novapax	Portare carrino vuoto e metalli fosfatati		
		Novapax	Prendere carrino pieno e portarlo in forno		
		Ass Dynamic	Portare carrino pieno da forno		
	8	Cella 1	Portare carrino vuoto e metalli fosfatati		
		Cella 2	Portare carrino vuoto e metalli fosfatati		
	9	Linea PSA	Portare isolation layer		
	10	Scarico carrino	Portare carrino pieno		
		Selezione	Portare pedana con componenti da selezionare		
		MA11 (ASSBMW)	Portare componenti per assemblaggio		
	2	Assemblaggio P6	Portare KLT, vassoi, pedana, coperchio e sacchetti		
	3	Coating	Portare KLT, vassoi, pedana, coperchio e sacchetti		
	4	Valeo	Portare KLT, vassoi, pedana, coperchio e sacchetti		
	5	Pressa 401	Portare KLT, vassoi, pedana, coperchio e sacchetti		
	6	Rettifica	Portare vassoi e sacchetti		
	7	Ass Dynamic	Portare scatole, pedana, sacchetti e distanziatori		
	9	Linea PSA	Portare pedana, coperchio e KLT + caricare su rastrelliera KLT vuote		
	10	Scarico carrino	Portare KLT, vassoi, pedana, coperchio e sacchetti		
		Selezione unipiston	Portare KLT e pedana		
		MA11 (ASSBMW)	Portare KLT e pedana		

Figure 5.16: New Work instruction for Runner

5.5.4 Visual dashboard for monitoring workflows

Following the analysis and definition of new logistic flows for production supply during the Runners' shifts, a visual system aimed at improving the organization and management of daily operations was implemented. For this reason, 13 information boards were installed inside the Chivasso (TO) plant, strategically placed at the workstations considered most critical to the proper functioning of the production process. The choice of areas in which to place these tools was based on an in-depth analysis.

The information boards were designed with the objective of providing support to the Runners, facilitating the management of the daily activities of line procurement and machine replenishment. With a clear and intuitive design, these tools enhance the usability of essential information and provide detailed visual guidance for internal material handling. Specifically, each bulletin board contains an updated production map highlighting the optimized routes to be followed for replenishment activities, the number and location of stops, and the workstations related to each flow. This organization allows operations to be further standardized, drastically reducing travel time and distances.

A key aspect of the information boards is detailed maps that primarily indicate the ideal internal material handling flow and also include the precise location of waste pickup points. In addition, through a visual system that echoes the theoretical concepts expressed in Chapter 1 regarding Visual Management, the bulletin board provides the Runner with a clear indication of his or her current location within the plant, improving orientation and facilitating more efficient movement between different work areas.

The introduction of this visual support system has led to significant improvement in several respects. First, it contributed to increased standardization of activities, ensuring that replenishment and handling operations followed predefined procedures shared by all operators. This proved particularly useful at shift change times, as it reduced dependence on verbal instructions and made information immediately accessible and understandable to incoming staff. Secondly, a better workload balance was achieved among the Runners, allowing a more equitable distribution of activities and reducing any work overloads that could have adversely affected the overall efficiency of the internal logistics system.

Another major benefit was found in time management and the reduction of non-value-added operations. The presence of clear and easily understood information made it possible to improve and thus speed up the process of picking and searching for the material needed for the production lines, avoiding wasted time due to misunderstandings or non-optimized routes.

In the next sections, the results obtained from the implementation of this system will be analyzed in detail, evaluating its impact in terms of reducing replenishment times, minimizing logistical errors and overall improvement in the ergonomics of the operations carried out by the Runners.

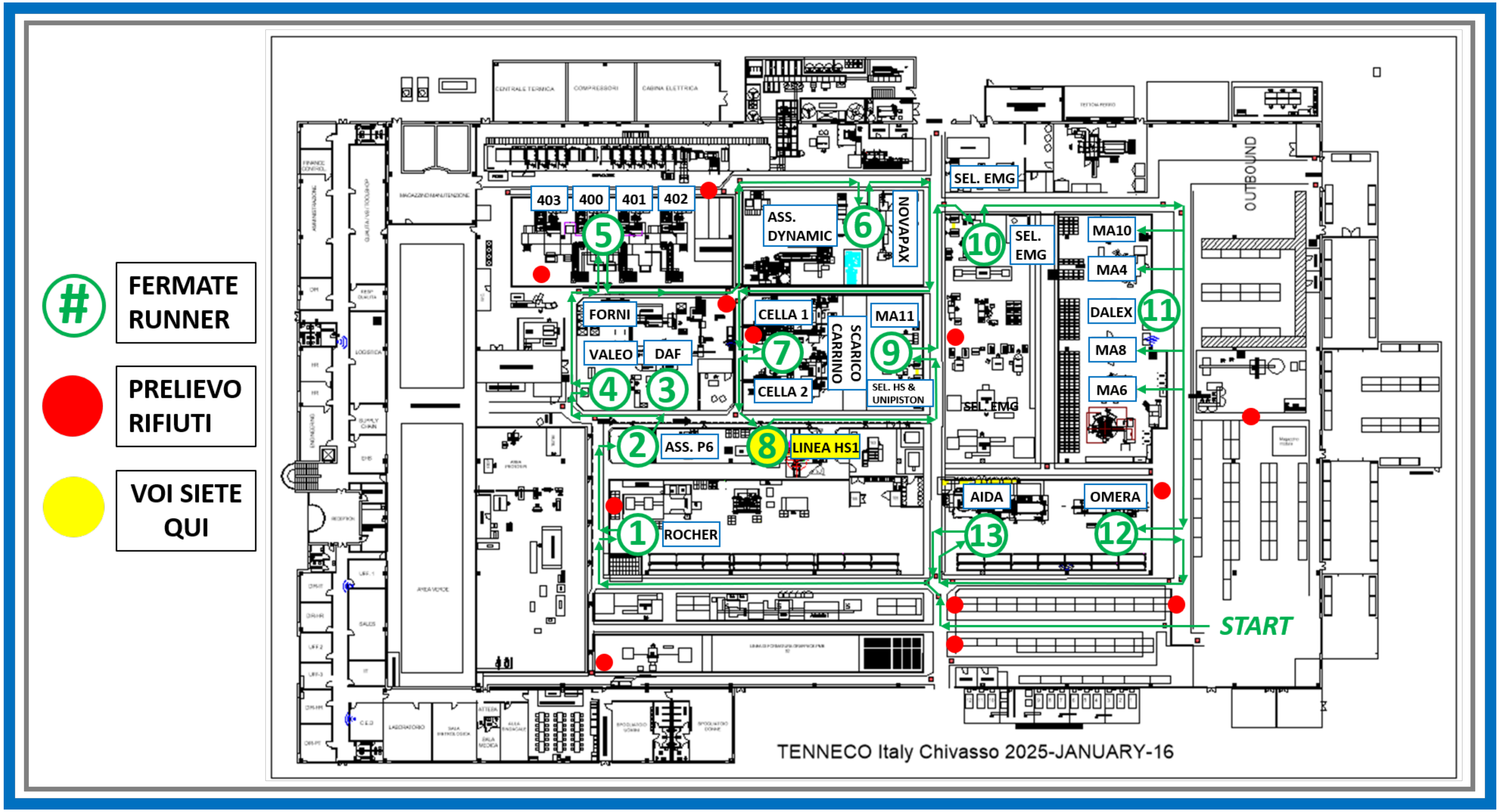


Figure 5.17: Flow optimization and Workstation labelling

Assigning an identification number to each workstation was of paramount importance in order to ensure a more structured and easily understood management of internal material replenishment and handling activities. This system, inspired by the model adopted for the numbering of public transportation stops, allows runners to find their way around the production area more quickly and easily, avoiding loss of time and reducing the likelihood of operational errors. The rationale by which the numbers were assigned to the locations was not defined randomly, but was the result of a careful analysis conducted during the Thesis Project. This analysis took into consideration several factors such as the frequency with which platforms and materials are moved on production lines and their economic impact on the company's turnover. In order to ensure a harmonious and balanced workflow, the layout of the stops was designed according to an optimized configuration, structured to form a "figure of eight" path. This choice was dictated by the need to minimize travel time, avoiding unnecessary movements and ensuring a continuous and orderly flow of replenishment operations. Such an organization allows for a more even distribution of the Runners' workload, reducing wasted time and energy, and ensuring that each operator follows a logical and predefined path.
To analyze the operation of this system in detail, one of the 13 bulletin boards installed in the plant is now examined, as the organizational and operational principle behind each is almost identical. The workstation considered is Line HS1, belonging to the Heat Shield department, which is responsible for the production of heat shields for endothermic engines for the Automotive and Truck sectors. The figure below shows the picture of the bulletin board associated with this specific workstation. As can be seen, the bulletin board clearly and prominently displays the stop identification number, the name of the workstation, the production department to which it belongs, a thumbnail map useful for orientation within the production area, and an image of the corresponding machine or operating line.

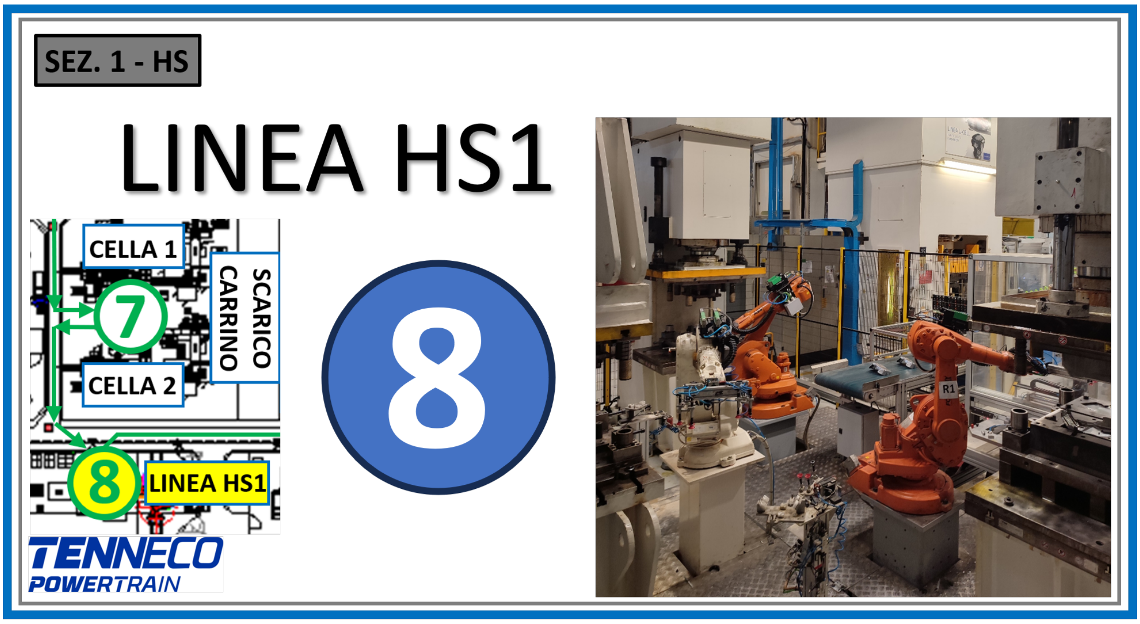


Figure 5.18: Dashboard main screen

Previously, the absence of an accurate identification system made it more complex for runners to immediately identify the machines to be restocked or the raw material pickup areas. In the following sections, the benefits obtained from the implementation of this system will be discussed in detail, with a focus on the analysis of performance before and after the introduction of information boards and stop numbering. The results obtained will be evaluated both in terms of reduced replenishment times and in relation to increased line productivity and overall plant efficiency. The implementation of the coin-operated system has proven to be very useful in standardizing and optimizing logistics operations within the plant. This system, based on clear and immediate interaction between the line operators and the Runners, makes it possible to drastically reduce the risk of errors and inefficiencies related to the management of material requests.
The proper use of the token box is based on a simple and effective principle: each line operator, at the time he needs a particular material, must pick up the corresponding magnetic token and place it in the Material Request section of the bulletin board associated with his workstation. The token is placed on the box corresponding to the code of the requested material, thus ensuring immediate visibility of the need by the Runner. The latter, following the predefined route and respecting the numerical order of the stops, easily identifies the requests on the board and plans his replenishment activity efficiently accordingly. Once the material delivery is completed, the Runner is responsible for taking the token from the request box and placing it back on the magnetic holder, thus signaling that the replenishment has been completed. This approach achieves several operational benefits. First, the visual management of requests, made possible by the use of tokens, significantly reduces the risk of misunderstandings or miscommunication between line operators and Runners, thus eliminating any delays due to incorrectly signaled requests or incorrectly delivered materials. In addition, the Runners' workflow is optimized, as they no longer have to interrupt their activities to receive verbal or telephone requests, but can plan deliveries in a more organized and simple manner. From a visual management perspective, the bulletin board screen was designed to ensure maximum clarity and usability of information. Products have been listed in alphanumeric order and categorized according to different end customers, allowing quick identification of the material needed and reducing the risk of errors in package selection and packaging for the latter.

Another advantage of the token system is its ability to ensure a continuous and balanced supply flow. The scheduling of runners in the three daily shifts is designed to meet production needs and possible emergencies, while maintaining an equitable distribution of the workload. For the system to work optimally, certain basic requirements must be met:

- The production department must not be uncovered for more than two consecutive hours, with the sole exception of the first shift in the morning (09:00 - 12:30), during which the Runner is engaged in dispatch activities;
- Based on operational needs and possible emergencies, the Runner may self-manage his or her schedule, after coordination with the dispatch and production departments;
- At least three hours of dispatch support must be guaranteed for each shift, again in compliance with the first requirement.

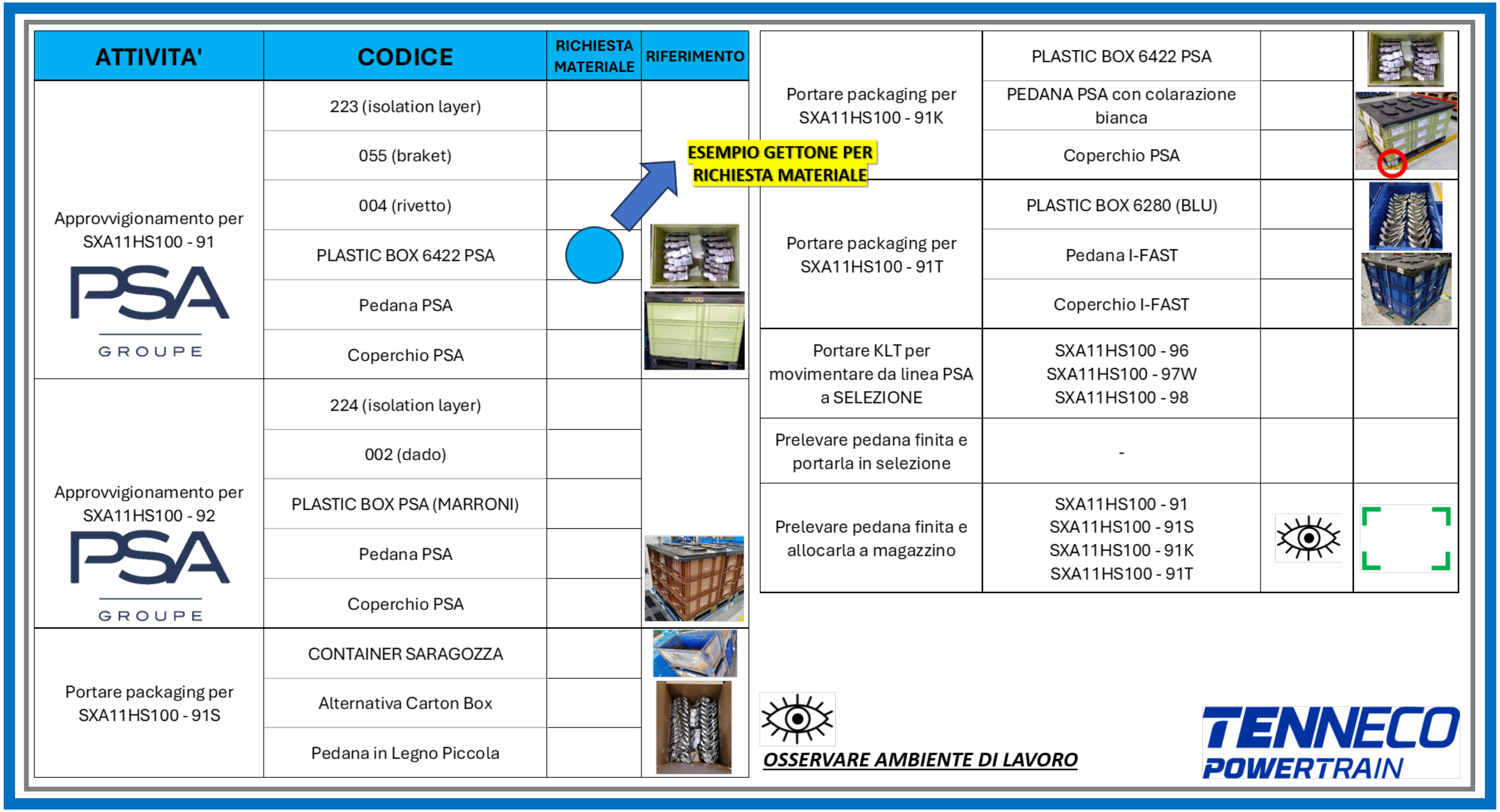


Figure 5.19: Screen for requesting material from the line

Adopting these rules with the token system ensures that the logistics flow is always under control, preventing situations of overload or production interruption due to lack of materials. The main advantage lies in the ability to efficiently act on needs within the production department, avoiding downtime and reducing operational costs associated with delays or inefficiencies in line replenishment.
In the following chapters, the impact of the introduction of this system on the overall productivity of the plant will be analyzed, with a focus on reducing waiting times, increasing operational efficiency and standardizing logistics activities. Data collected through performance monitoring before and after the implementation of the system will also be presented in order to assess the benefits achieved. Subsequently, due to messes and confusions within the plant, additional representations were implemented on the proper placement of platforms and materials at the edge of the line and near the workstations in order to ensure a clean, orderly place and always in line with the concepts taken up in Chapter 1 regarding 5S and Visual Management. By doing so, there is continuous improvement for the cleanliness and orderliness of workstations consequently increasing production efficiency and the safety and health of all operators. As shown in the figure below, slides have been included regarding the legend for correct positioning of platforms and materials at the machine.

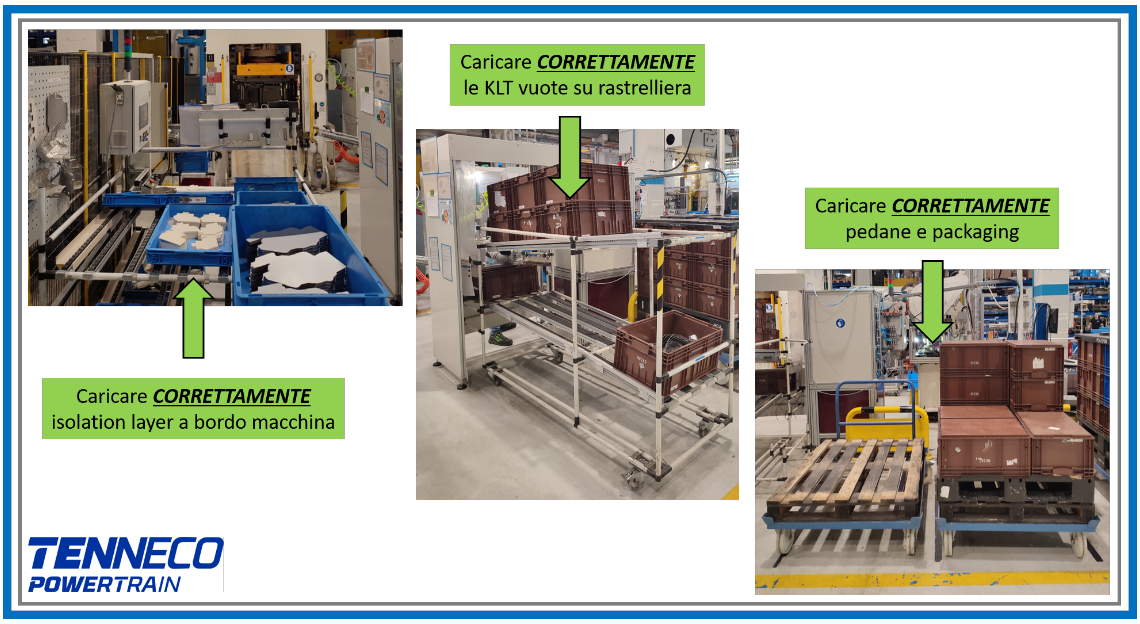


Figure 5.20: Legend for correct positioning of items

Finally, for safety and visual management reasons, legends have been added to the bulletin board regarding the color codes used for floor markings within the production facility. Despite hours of training by safety officers and constant urging by Superiors to constantly comply with the signs posted on the floor according to the various colors, many operators still do not comply with them causing discomfort and danger to the health and safety of all operators within the plant. There is also a lot of confusion between the various platforms and all the materials that need to be moved within the production area because sometimes they do not correspond to what the floor markings are signaling at that moment.

All this therefore leads to confusion, misunderstanding in the handling and picking of the pallets and therefore causes inefficiencies in terms of time and distances traveled in activities that do not bring any added value to production.

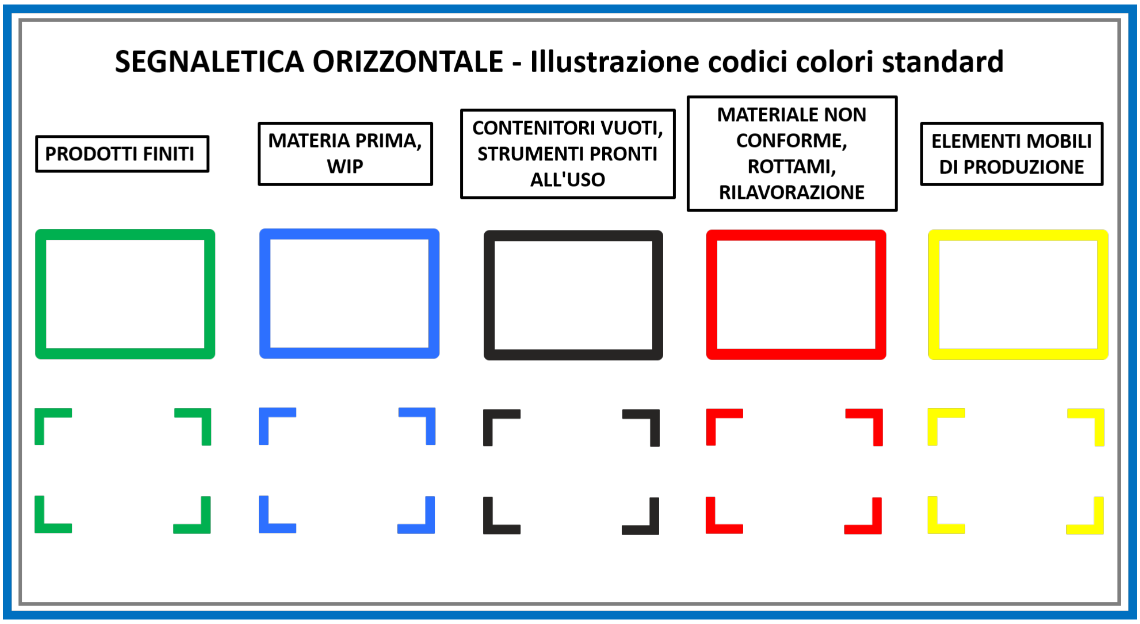
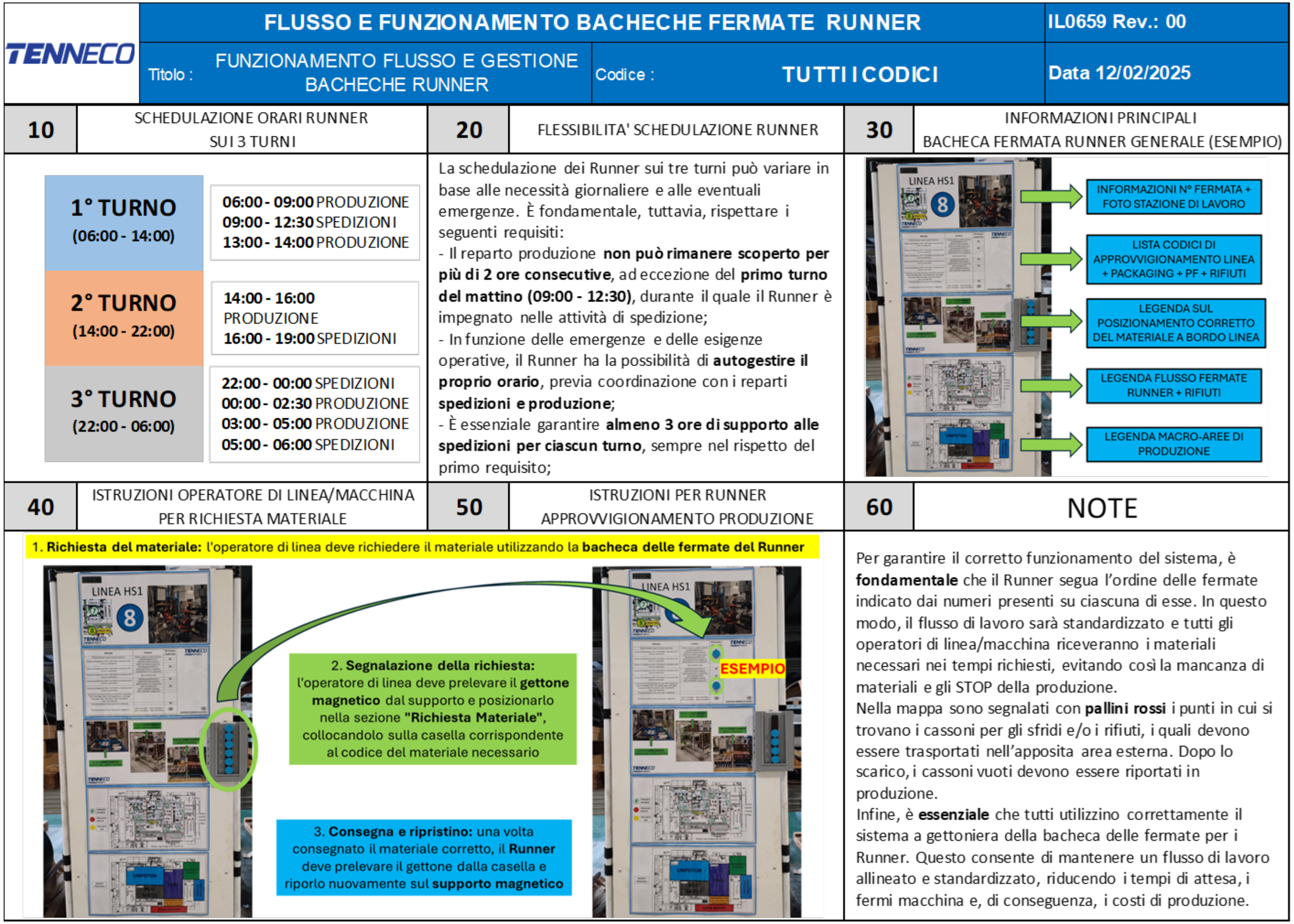


Figure 5.21: Recall of the horizontal road marking legend

Once the thesis project was concluded and the implementation and design of the new material recall and line supply system was also completed, it was necessary to train all operators, supervisors, managers, and all those in the production area in order to be all aligned with the new work instructions and work cohesively and harmoniously among all production departments. Below, the figure below shows the plan of work instructions that I personally created and were disseminated within the entire production department and the plant itself so as to ensure considerable effectiveness in managing the new system through bulletin boards for requesting material from the production lines. All people were trained through this work instruction sheet during a period of about a month as there being 3 daily shifts working continuously for 24h, the logistical time needed to conduct a training to all operators could only be that.



TENNECO | **FLUSSO E FUNZIONAMENTO BACHECHE FERMATE RUNNER** | **IL0659 Rev.: 00**

Titolo : FUNZIONAMENTO FLUSSO E GESTIONE BACHECHE RUNNER | Codice : **TUTTI I CODICI** | **Data 12/02/2025**

10 SCHEDULAZIONE ORARI RUNNER SUI 3 TURNI

1° TURNO (06:00 - 14:00)	**06:00 - 09:00** PRODUZIONE **09:00 - 12:30** SPEDIZIONI **13:00 - 14:00** PRODUZIONE
2° TURNO (14:00 - 22:00)	**14:00 - 16:00** PRODUZIONE **16:00 - 19:00** SPEDIZIONI
3° TURNO (22:00 - 06:00)	**22:00 - 00:00** SPEDIZIONI **00:00 - 02:30** PRODUZIONE **03:00 - 05:00** PRODUZIONE **05:00 - 06:00** SPEDIZIONI

20 FLESSIBILITA' SCHEDULAZIONE RUNNER

La schedulazione dei Runner sui tre turni può variare in base alle necessità giornaliere e alle eventuali emergenze. È fondamentale, tuttavia, rispettare i seguenti requisiti:

- Il reparto produzione **non può rimanere scoperto per più di 2 ore consecutive**, ad eccezione del **primo turno del mattino (09:00 - 12:30)**, durante il quale il Runner è impegnato nelle attività di spedizione;
- In funzione delle emergenze e delle esigenze operative, il Runner ha la possibilità di **autogestire il proprio orario**, previa coordinazione con i reparti **spedizioni e produzione**;
- È essenziale garantire **almeno 3 ore di supporto alle spedizioni per ciascun turno**, sempre nel rispetto del primo requisito;

30 INFORMAZIONI PRINCIPALI BACHECA FERMATA RUNNER GENERALE (ESEMPIO)

40 ISTRUZIONI OPERATORE DI LINEA/MACCHINA PER RICHIESTA MATERIALE | **50** ISTRUZIONI PER RUNNER APPROVVIGIONAMENTO PRODUZIONE

1. **Richiesta del materiale:** l'operatore di linea deve richiedere il materiale utilizzando la **bacheca delle fermate del Runner**

2. **Segnalazione della richiesta:** l'operatore di linea deve prelevare il **gettone magnetico** dal supporto e posizionarlo nella sezione **"Richiesta Materiale"**, collocandolo sulla casella corrispondente al codice del materiale necessario

3. **Consegna e ripristino:** una volta consegnato il materiale corretto, il **Runner** deve prelevare il gettone dalla casella e riporlo nuovamente sul **supporto magnetico**

60 NOTE

Per garantire il corretto funzionamento del sistema, è **fondamentale** che il Runner segua l'ordine delle fermate indicato dai numeri presenti su ciascuna di esse. In questo modo, il flusso di lavoro sarà standardizzato e tutti gli operatori di linea/macchina riceveranno i materiali necessari nei tempi richiesti, evitando così la mancanza di materiali e gli STOP della produzione.

Nella mappa sono segnalati con **pallini rossi** i punti in cui si trovano i cassoni per gli sfridi e/o i rifiuti, i quali devono essere trasportati nell'apposita area esterna. Dopo lo scarico, i cassoni vuoti devono essere riportati in produzione.

Infine, è **essenziale** che tutti utilizzino correttamente il sistema a gettoniera della bacheca delle fermate per i Runner. Questo consente di mantenere un flusso di lavoro allineato e standardizzato, riducendo i tempi di attesa, i fermi macchina e, di conseguenza, i costi di produzione.

Figure 5.22: Runner Work instruction for Milk-Run

5.5.5 Analysis of the results and ROI

Analysis of the benefits obtained as a result of the implementation of the new internal logistics system shows a significant increase in the plant's operational efficiency. Through Project Runner, it was possible to optimize the handling flows of pallets and materials destined for production, eliminating inefficiencies and reducing unnecessary operational costs.
To analyze the benefits through this optimization brought about by this Thesis Project, it was necessary to make some assumptions and considerations about the company's work shifts and production activity. Considering that in a calendar year a company in the Automotive sector operates for about 48 working weeks, and taking into account the weekly division of shifts, the production system of the plant under consideration involves a total of 16 shifts of 8 hours each. This pattern consists of three daily shifts from Monday to Friday (06:00-14:00, 14:00-22:00, 22:00-06:00) and one shift on Saturday mornings (06:00-14:00), for a total of 128 working hours per week. During the 4-week observation period, it was found that the Runner performed an average of 3 rounds per shift, each dedicated to raw material procurement, handling the platforms for packaging finished products, and handling semi-finished products along the production lines. Thanks to the introduction of the Milk-Run system, route optimization has drastically reduced the time spent on activities with no added value.
The savings achieved can be divided into two main categories: reduction in labor hours spent on internal handling and decrease in energy costs associated with the use of internal transportation. As shown in the calculation table, thanks to the new logistics system, the company achieved an estimated annual savings of about 37,000€. Of this figure, about 34,500€ comes from the reduction in handling hours, since, thanks to the new transportation method, each runner's turn saved about 1.5 hours compared to the previous system. Multiplying this value by the number of rounds made per shift and considering the company's entire annual hours, the final value of labour cost savings was arrived at. At the same time, there was a significant reduction in energy consumption related to internal handling equipment. Taking an electric forklift Still RX 60-40 as a reference, with an average annual mileage of 14,500 km, energy consumption was calculated to be between 7 and 7.5 kWh per hour. Considering an average speed of about 10 km/h, the consumption per kilometer driven turns out to be about 0.75 kWh/km. On an annual basis, this translates into an estimated total consumption of 10,875 kWh. Assuming an average cost of electricity for companies in northern Italy of €0.23-0.24/kWh, this results in an annual cost of powering a single forklift of between €2,500 and €2,600.

By reducing the distances travelled and eliminating empty trips, the new system has thus contributed to a drastic reduction in energy consumption and, consequently, a reduction in operating costs.

WORKING WEEKS / YEAR	48		WORKING WEEKS / YEAR	48	
WORKING SHIFTS / WEEK	16	Mon - Fri (06:00-14:00, 14:00-22:00, 22:00-06:00) + Sat (06:00-14:00)	WORKING SHIFTS / WEEK	16	Mon - Fri (06:00-14:00, 14:00-22:00, 22:00-06:00) + Sat (06:00-14:00)
ROUNDS / SHIFT	3		ROUNDS / SHIFT	3	
HOURS / ROUND	1,5	positive DELTA btw previous and actual configuration	METERS / ROUND	6260	positive DELTA btw previous and actual configuration
HOURS / YEAR	3456	positive DELTA btw previous and actual configuration	KM /YEAR	14500	positive DELTA btw previous and actual configuration
TOT € SAVED / YEAR	34560	TOT annual saving for the Company	TOT € SAVED / YEAR	2500	TOT annual saving for the Company

Figure 5.23: Savings and ROI

The introduction of the new intercompany milk-run system, made possible by the company's investment in the purchase of the toy train and related wagons, inevitably entailed initial costs associated with negotiating with suppliers and supplying the new means of transportation. However, as the analyses conducted showed, the benefits achieved in terms of operational efficiency and cost reduction amply justified the investment.
By analyzing the issue from an economic and financial perspective and applying a return on investment (ROI) analysis, it was possible to determine that the entire cost incurred in implementing the new logistics system was amortized in just over three months. This was achieved due to tangible savings resulting from the reduction in labor hours devoted to internal handling, reduced energy costs. The improved efficiency also generated a positive impact on the continuity of the production flow, minimizing waiting times for material procurement and thus reducing delays in assembly and packaging operations. A further significant economic benefit was achieved through the reorganization of the raw materials warehouse, as described in Chapter 3, by implementing optimized management based on the FIFO (First In, First Out) principle. This upgrade made it possible to reduce the need for personnel dedicated to logistics operations, leading to a cut of one work unit and providing annual savings of more than €25,000. The elimination of this position was made possible by the new platform handling system, the reduction in the distances traveled daily by operators, and the increased efficiency in organizing storage space. The remaining staff was able to handle the same tasks in less time, resulting in increased productivity.

In addition, another key aspect that contributed to the optimization of the production process was the improved layout of workstations according to the needs of the production lines. The redesign of the locations of spaces inside production, carried out according to the classification and coding of materials, has made operators' activities more ergonomic and intuitive, facilitating the picking of components and reducing unnecessary time and movements. The reorganization of routes and the reduction of distances traveled have allowed a drastic decrease in picking times while improving operator productivity and safety at work, an issue that is close to the company.

Thanks to this redesign and improvement of space and logistics flows, it was possible to eliminate many activities with no added value that the company, until then, incurred annually as unnecessary operating costs.

We conclude this chapter, and with it the entire thesis project, by summarizing the capital recovered through this challenging project completed over a 5-month period at the Tenneco plant in Chivasso (TO). During the project, several improvement activities aimed at increasing production efficiency, optimizing logistics flows, and reducing business costs were implemented. These initiatives led to tangible results, measurable both in terms of time saved and economic impact. This result demonstrates the significant impact of optimization and continuous improvement activities applied at the plant. The methodology used made it possible to identify inefficiencies, develop concrete solutions and achieve benefits in terms of both economic and production efficiency. The entire project was based on the application of Lean Manufacturing, Visual Management and 5S principles, which are fundamental to ensuring order, cleanliness and standardization within the plant. In addition, the definition of optimized flows for the Runners and the introduction of the token system made the replenishment of production lines faster and more accurate, avoiding downtime and improving overall productivity. In conclusion, this project represents a concrete case of continuous improvement applied to logistics and production management, with tangible and measurable results that have had a direct impact on the company's bottom line.

IMPROVEMENT ACTIVITIES	RESULTS	TANGIBLE IMPACT	AREA OF INTEREST
Reorganization of Warehouse Goods: FIFO System Implementation	Reduction of Time in Searching & Picking Activities	5.000 hours/year 50.000 €/year	LOGISTICS
Reorganization of Coils: Aida & Omera: FIFO System Implementation	Reduction of Time in Operating, Searching & Picking Activities	1.500 hours/year 15.000 €/year	PRODUCTION / LOGISTICS
Optimization of Heat Shield Area	Reduction of Time in Working hours and Reworking Activities	23.000 €/year	PRODUCTION / LOGISTICS
Obsolete Stock Analysis and Optimization of Storage Space	Estimated residual value of materials	180.000 €	FINANCE
Rack allocation near Workstation Ass. P6	Reduction of Time in Working Activities	400 €/year	PRODUCTION / LOGISTICS
Optimization and Re-design of internal logistics flows	Reduction in material handling activities and relative Working hours	34.500 €/year	PRODUCTION / LOGISTICS
Optimization and Re-design of internal logistics flows	Reduction in material handling activities and relative consumption of the electric forklift	2.500 €/year	PRODUCTION / LOGISTICS
TOT Saving € / year		125.400,00 €	
TOT Saving € for selling Activieites (Obsolete Materials, *una tantum*)		180.000,00 €	
TOT Saving € (THESIS PROJECT)		**305.400,00 €**	

Figure 5.24: Thesis Project TOT € Saving

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