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Lean-Oriented Optimization and Automation of Internal Logistics Flows in an Automotive Manufacturing Environment

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Abstract

This thesis examines the optimization of internal logistics flows within an automotive manufacturing environment, focusing on the integration between logistics operations and production processes. Based on Lean principles, the study aims to transform a non-standardized material handling system into a structured, standardized, and partially automated logistics configuration.

The research was conducted in a plant specialized in engine-related components for major automotive manufacturers. Initial analysis showed that internal logistics activities, managed by a dedicated operator (runner), were characterized by high variability, absence of standardized routes, and dependence on verbal communication. Material replenishment, semi-finished transfers, finished goods handling, and scrap removal were performed without predefined scheduling logic, generating fragmented movements and inefficiencies.

The improvement process followed several methodological phases. First, the current configuration (AS-IS) was analyzed by mapping material flows from inbound receipt to finished goods shipment. GPS monitoring and spaghetti chart analysis were used to visualize transport paths and identify waste related to motion, transportation, and task interruptions. Attention was paid to warehouse organization and runner workload distribution.

A warehouse reorganization was then implemented to improve material allocation and accessibility, aligning storage logic with consumption frequency and proximity to production lines. This intervention enabled the design of a standardized internal replenishment route based on milk-run principles.

Runner activities were subsequently redesigned through the introduction of a cyclic and structured route aimed at stabilizing supply intervals, reducing unplanned production requests, and improving workload predictability. Scrap handling, raw material supply, and finished goods transport were integrated into a coordinated internal loop to support flow continuity.

Finally, it was evaluated the feasibility of introducing collaborative and automated transport systems. Automation was considered as complementary support to standardized processes rather than a full replacement of human operators. A technical and economic assessment was conducted to estimate investment requirements and potential operational benefits.

The results demonstrate that aligning warehouse layout, standardized transport routes, and Lean-oriented logistics principles significantly enhances flow stability and operational efficiency. This work proposes a structured and replicable approach for optimizing internal logistics systems in complex manufacturing environments.

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Introduction

The aim of this thesis is to analyze, improve, and optimize the internal logistics flow of a manufacturing company operating in the automotive sector and specialized in the production of components supplied to major automotive manufacturers. In particular, the study focuses on the optimization of production line replenishment activities and on the integration between internal logistics and production processes, which represent key factors in achieving high levels of operational efficiency.

The study was developed through a series of fundamental methodological steps. In the first phase, the overall logistics flow of the company was analyzed by tracing the material path from its entry into the plant as raw material, through the subsequent processing stages, until its transformation into a finished product. This analysis made it possible to reconstruct the path followed by each material within the company, providing a structured overview of the initial logistics configuration (AS-IS). This approach is consistent with Lean Manufacturing principles, according to which a thorough understanding of physical flows represents the starting point for waste identification and the definition of targeted improvement actions.

Within the analyzed context, material handling activities are carried out by the *runner*, who is responsible for supplying machines with raw materials, transferring semi-finished products between production lines, and transporting finished goods to the shipping area. The preliminary analysis revealed that these activities were not governed by a structured and standardized planning system but were mainly managed in a reactive manner based on immediate needs. This operating mode generated confusion in the *runner*'s workflow and several inefficiencies, resulting in delays in line replenishment and, consequently, in slowdowns of the overall production process. Moreover, the lack of clear operational standards increased system variability, making performance highly dependent on individual operator experience.

The second step of the study involved a more detailed analysis of the *runner*'s daily activities. Specifically, the route followed during the work shift and the performed operations were monitored using a GPS-based tracking system. This activity enabled the development of a spaghetti chart, an analytical tool used to graphically represent actual movement paths within the facility, allowing the identification of non-value-added movements and flows characterized by frequent interruptions or unnecessary backtracking. The spaghetti chart provided an objective basis for the subsequent redesign of logistics flows and layout.

The third step of the study focused on the reorganization of material storage areas, with particular attention to warehouses and shelving systems within the company. Material storage represents one of the key elements in logistics process optimization, as it enables the reduction of unnecessary movements, improves material accessibility, and minimizes overall product

handling. A more rational management of warehouse spaces also contributes to reduced picking times and supports a more reliable and regular logistics flow.

This intervention provided a structured and coherent foundation for defining an optimal *runner* route, closely linked to the overall optimization of the internal logistics flow. The alignment between layout, storage methods, and handling routes represents a fundamental prerequisite for the application of Lean principles oriented toward continuous flow and waste reduction.

Finally, the last step of the study involved the development of a concrete proposal concerning the introduction of robotized transportation systems within the company. This solution was evaluated with the aim of reallocating human resources toward higher value-added activities, reducing unplanned idle times, and minimizing time losses associated with manual handling operations. Automation was analyzed as a support tool for the existing logistics system, with the objective of improving operational continuity without fully replacing human operators.

At the conclusion of the study, an economic analysis was conducted to assess the benefits achieved following the implementation of the proposed improvement actions, both from a production and an economic perspective. The analysis also considered the economic feasibility of introducing collaborative systems for product handling, evaluating their impact in terms of investment costs, expected operational savings, and potential medium-term economic returns.

Overall, this work aims to define a structured and replicable approach for the optimization of internal logistics flows in manufacturing environments, highlighting how the effective integration of logistics, layout, and production processes can significantly enhance operational performance.

1 Introduction

This chapter introduces the theoretical framework adopted in this thesis to provide the conceptual background necessary for understanding the subsequent analysis and case study. The topics presented aim to clarify the principles and managerial approaches that underpin flow-oriented manufacturing systems, with particular attention to continuous improvement and the management of material and information flows.

The chapter begins with an overview of Total Flow Management and Kaizen principles, which provide a systemic perspective on process stability and continuous improvement. It then introduces the fundamental principles of Lean Manufacturing, focusing on waste reduction, flow continuity, and standardization. Building on these concepts, the chapter progressively narrows its focus to internal logistics and material flow management, examining how structured logistics systems support production performance.

Finally, the chapter presents the main Lean tools and logistics concepts that will be referenced in later sections of the thesis. This theoretical foundation is intended to support the analysis of internal logistics processes and the improvement actions discussed in the case study, ensuring conceptual consistency between theory and practical application.

1.1 Total Flow Management and Kaizen Principles

Total Flow Management (TFM) can be defined as a systemic approach to managing industrial processes with the objective of ensuring continuity, stability, and coherence of flows across the entire production system [1]. Rather than focusing on the optimization of individual processes or departments, TFM emphasizes the management of end-to-end flows, considering production, logistics, and support activities as interdependent elements of a single system.

At the core of Total Flow Management lies the assumption that overall system performance is primarily determined by the quality and stability of flows rather than by local efficiencies. Improvements applied in isolation may generate short-term gains at a local level but often fail to translate into sustainable system-wide performance. TFM therefore promotes a holistic perspective, in which decisions are evaluated based on their impact on the entire value creation process.

A fundamental principle underpinning Total Flow Management is Kaizen [2], commonly translated as continuous improvement. Kaizen does not represent a specific tool or methodology, but rather a managerial and cultural approach based on the pursuit of incremental improvements through the systematic identification and elimination of inefficiencies. Within a

TFM framework, Kaizen supports the continuous refinement of processes by encouraging problem visibility, standardization, and learning at all organizational levels.

Unlike improvement approaches based on radical or episodic change, Kaizen emphasizes gradual and sustained progress. This perspective is particularly relevant in complex manufacturing environments, where stability and repeatability are prerequisites for effective improvement. By fostering a culture in which deviations from standard conditions are treated as opportunities for learning rather than exceptions to be managed, Kaizen contributes to the long-term robustness of the production system.

Total Flow Management integrates Kaizen principles into a structured framework aimed at aligning people, processes, and material flows. From this perspective, improvement activities are not limited to production operations but extend to logistics, material handling, information flow, and layout design. The objective is not merely to increase efficiency at specific workstations, but to ensure that all activities contribute coherently to the smooth progression of materials and information through the system.

Another key aspect of TFM is its focus on flow stability. Variability in production volumes, material supply, or process execution introduces disruptions that propagate across the system, generating delays, excess inventory, and reactive behaviors. Total Flow Management addresses this issue by promoting standardized processes, clear flow structures, and consistent operating conditions. Stability is therefore viewed not as a constraint on flexibility, but as an enabling condition for effective and sustainable improvement.

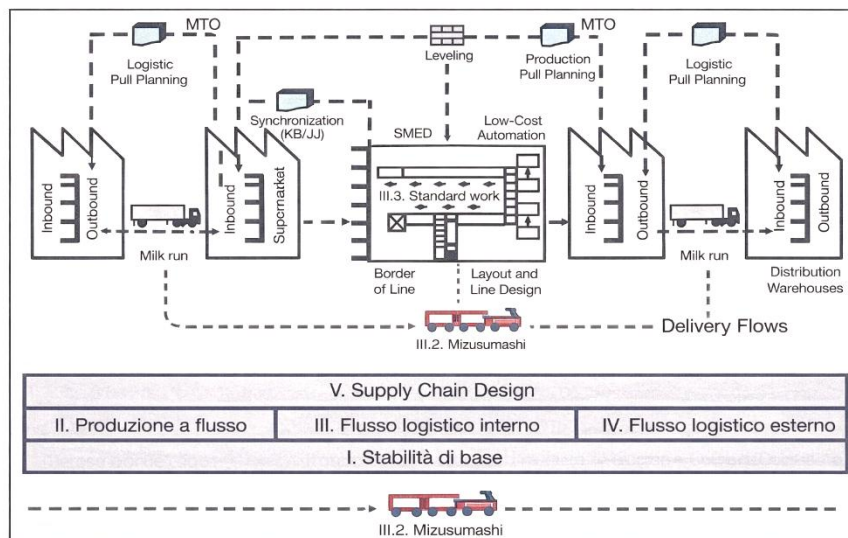


Figure 1.1 – An example of the TFM model representation [1]

Within this framework, the role of management is to create the conditions that allow flows to operate as designed [3]. This includes defining clear process ownership, establishing performance indicators aligned with flow objectives, and supporting continuous improvement

initiatives through structured problem-solving. Employees, in turn, are encouraged to actively participate in identifying deviations, proposing improvements, and maintaining standard conditions.

In summary, Total Flow Management provides a conceptual foundation for understanding manufacturing systems as integrated networks of flows rather than collections of isolated activities. By combining a systemic view of processes with the continuous improvement principles of Kaizen, TFM establishes the conditions for stable, predictable, and continuously improving operations. This perspective forms the basis for the subsequent analysis of Lean Manufacturing principles and their application to internal logistics and material flow management, which are addressed in the following chapters.

1.2 Lean Manufacturing Principles

Lean Manufacturing represents a managerial and operational approach aimed at improving system performance through the systematic elimination of waste and the continuous enhancement of value-creating activities. Unlike traditional efficiency-driven models, Lean Manufacturing does not focus on maximizing the performance of individual processes or resources, but rather on improving the overall behavior of the production system.

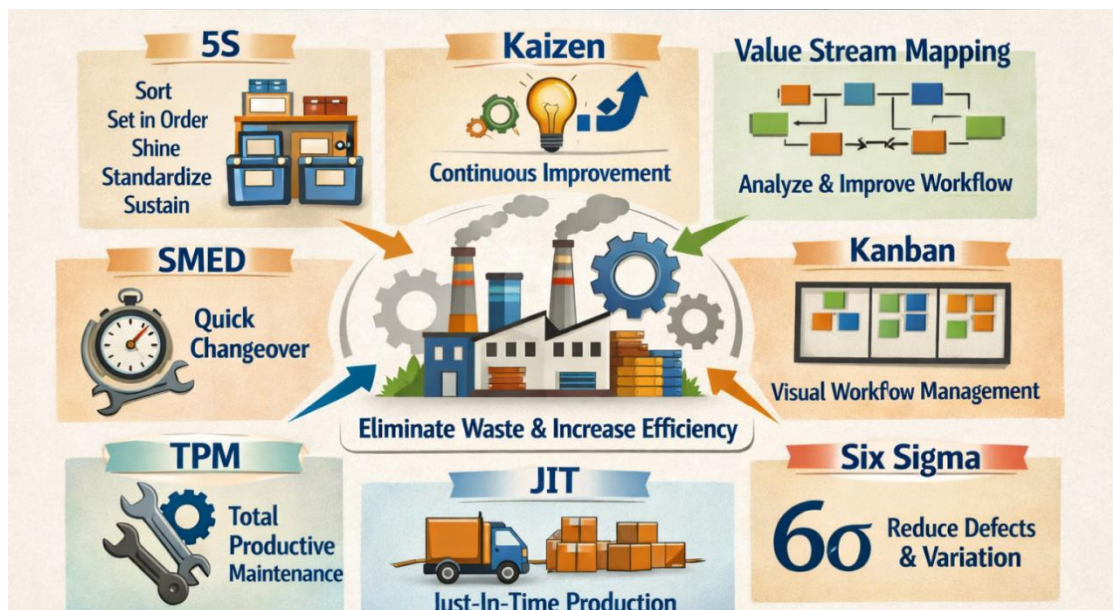


Figure 1.2 – Lean Manufacturing Tools

One of the core principles of Lean Manufacturing is the definition of value from the customer's perspective [4]. Only activities that directly contribute to fulfilling customer requirements are considered value-adding. All other activities consume resources without increasing the value of the final product and are therefore classified as waste. This perspective shifts the focus of

improvement efforts from local efficiency metrics to the ability of the system to deliver value in a reliable and timely manner.

Waste in Lean Manufacturing is not limited to obvious inefficiencies or errors. It also includes activities that are embedded in standard operations but do not contribute to value creation, such as excessive handling, waiting times, overprocessing, and unnecessary movement. While some of these activities may be unavoidable under current technical or organizational constraints, Lean Manufacturing aims to progressively reduce their impact through process redesign and standardization [5].

Another fundamental principle of Lean Manufacturing is the emphasis on flow. Flow refers to the continuous and uninterrupted progression of materials, information, and work through the production system. From a Lean perspective, disruptions to flow—such as bottlenecks, imbalances, or uncoordinated activities—are primary sources of waste and instability. Improving flow therefore becomes a central objective, as it directly affects lead time, responsiveness, and system predictability.

Flow-oriented thinking requires moving beyond traditional departmental or functional boundaries. Lean Manufacturing encourages the analysis of processes across their entire value stream, recognizing that inefficiencies often emerge at the interfaces between activities rather than within individual operations. This systemic view aligns with the Total Flow Management perspective introduced in the previous section, reinforcing the idea that performance improvements must be evaluated at the system level.

Standardization plays a critical role in supporting Lean principles. Standardized processes establish a stable baseline for operations, making deviations visible and enabling structured problem-solving. Rather than limiting flexibility, standardization provides a reference condition from which improvement can occur. Without stable and repeatable processes, variability increases and continuous improvement efforts become difficult to sustain [6].

Lean Manufacturing also places strong emphasis on process stability. Variability in demand, execution, or supply conditions introduces uncertainty that propagates throughout the production system. This instability often leads to reactive behaviors, such as expediting, excess inventory, or frequent rescheduling, which further increase waste. Lean principles therefore promote stability as a prerequisite for improvement, enabling processes to operate as designed and allowing problems to be addressed systematically.

Within this framework, people play a central role in sustaining Lean Manufacturing. Operators and support functions are not merely executors of predefined tasks, but active contributors to process improvement. Lean organizations encourage problem identification at the operational level and promote structured feedback loops between execution and management. This human-centered approach supports continuous improvement while reinforcing ownership and accountability across the organization.

In summary, Lean Manufacturing provides a coherent set of principles focused on value creation, waste reduction, flow continuity, standardization, and process stability. These principles establish the conceptual foundation for understanding why internal logistics and material flow management are critical elements of manufacturing performance. Building on this foundation, the following chapter examines internal logistics flows and supply mechanisms as key enablers of Lean-oriented production systems.

1.3 Internal Logistic Flow

Building on the principles of Total Flow Management and Lean Manufacturing discussed in the previous chapters, this section focuses on the role of internal logistics as a key enabler of flow-oriented production systems. It examines how different approaches to material supply, flow control, and logistics planning influence production stability and overall system performance. Attention is given to the transition from traditional, inventory-driven logistics toward structured, pull-based internal logistics solutions.

1.3.1 Traditional Supply versus Flow-Oriented Supply Systems

Internal logistics systems play a decisive role in determining the effectiveness of manufacturing operations, as they directly influence the availability of materials at production workstations and the continuity of production processes. The way materials are supplied to production lines reflects underlying managerial assumptions about efficiency, control, and variability. For this reason, it is useful to distinguish between traditional supply systems and flow-oriented supply systems, as they embody fundamentally different approaches to internal logistics management.

Traditional material supply systems are typically characterized by inventory-driven logic. In this approach, materials are delivered to production areas in relatively large batches and stored close to workstations in order to ensure availability. Replenishment activities are often triggered by forecast-based planning or by reactive requests from production operators when materials are running low. While this model may reduce the perceived risk of shortages, it generally leads to high inventory levels, extensive use of floor space, and limited visibility of actual material consumption [7].

From a system perspective, traditional supply methods tend to decouple logistics activities from real production demand. The accumulation of materials near the line may temporarily mask supply problems, but it also conceals inefficiencies such as unbalanced consumption rates, poor coordination between departments, and unstable production schedules. As a result, logistics activities become largely reactive, with material handling resources responding to urgent needs rather than following a structured and predictable flow.

In contrast, flow-oriented supply systems are designed to align material replenishment with actual production consumption. Rather than relying on large buffers, these systems aim to deliver materials in smaller quantities and at higher frequencies, synchronizing logistics activities with production requirements. The objective is not to eliminate inventory entirely, but to control it in a way that supports continuous flow while minimizing waste.

Flow-oriented supply shifts the focus of internal logistics from material availability to material movement. In this model, the effectiveness of logistics is measured not by the amount of stock held, but by the reliability and regularity with which materials reach the point of use. This approach requires a higher level of coordination between production and logistics functions, as well as greater discipline in process execution [7].

One of the key advantages of flow-oriented supply systems is their ability to make problems visible. By reducing excess inventory and limiting uncontrolled buffers, disruptions in material flow—such as delays, imbalances, or consumption anomalies—emerge more clearly. This visibility supports continuous improvement by enabling timely identification of root causes and structured corrective actions, in line with Lean Manufacturing and Total Flow Management principles.

However, transitioning from traditional to flow-oriented supply is not merely a matter of reducing inventory levels. It requires a redefinition of logistics roles, standardized replenishment processes, and clear rules governing material flow. Without these elements, attempts to reduce stock may increase instability rather than improve performance. For this reason, flow-oriented supply systems must be supported by appropriate control mechanisms and organizational structures, which are discussed in the following sections.

In summary, traditional supply systems prioritize inventory as a means of ensuring material availability, often at the expense of flow efficiency and transparency. Flow-oriented supply systems, by contrast, focus on synchronizing material movement with production demand, promoting stability, visibility, and waste reduction. This shift represents a fundamental change in internal logistics management and provides the foundation for the concepts of supermarkets, standardized replenishment roles, and pull-based planning introduced in the subsequent sections of this chapter.

1.3.2 The Supermarket concept

In flow-oriented internal logistics systems, inventory is no longer treated as a passive buffer aimed at protecting production from variability. Instead, it is deliberately structured to regulate material flow and to coordinate logistics activities with actual production demand. Within this framework, the supermarket concept represents a key mechanism for controlling material availability while preserving flow continuity.

A supermarket is a controlled inventory area positioned between upstream supply processes and downstream production consumption. Its function is to decouple processes operating at different rhythms without disconnecting them from real demand. Materials are withdrawn by production according to actual usage, and replenishment is triggered to restore predefined inventory levels. In this way, the supermarket transforms inventory from a static storage solution into an active element of flow regulation.

Unlike traditional line-side storage, supermarkets are governed by explicit rules concerning quantities, locations, and replenishment logic. Inventory levels are intentionally limited and standardized, preventing uncontrolled accumulation of materials near workstations. This structure reduces space occupation, simplifies material handling, and improves visibility of consumption patterns, making deviations from expected conditions easier to detect.

From a system perspective, the supermarket acts as an interface between production and logistics. It translates production consumption into structured replenishment requirements, allowing logistics activities to operate according to planned cycles rather than reactive requests. This reduces variability in material handling operations and supports a more predictable logistics workload.

An important consequence of supermarket-based supply is the increased exposure of process instability. By limiting excess inventory, supermarkets prevent problems from being hidden behind large buffers. Shortages, imbalances, or abnormal consumption patterns become visible more quickly, enabling timely corrective actions. This characteristic aligns with Lean and Total Flow Management principles, which emphasize problem visibility as a prerequisite for continuous improvement.

In summary, the supermarket concept provides a structured method for controlling inventory while supporting flow-oriented internal logistics. By regulating material availability and linking replenishment to real consumption, supermarkets enable stable and predictable logistics operations. This controlled environment creates the conditions for standardized replenishment roles and synchronized delivery cycles, which are examined in the following section.

1.3.3 Mizusumashi and Flow Stabilization

The introduction of flow-oriented supply systems and supermarket-based inventory control creates structural conditions for improved internal logistics; however, these elements alone are not sufficient to ensure stable and reliable material flows. To translate flow control mechanisms into daily operations, a coordinated approach is required that addresses both execution and variability management. Within this context, the concepts of mizusumashi, synchronization, and production leveling represent complementary elements of a unified flow stabilization strategy.

The mizusumashi, often referred to as the *runner*, is a dedicated logistics role responsible for executing standardized material replenishment activities along predefined routes. Unlike reactive material handling, where logistics activities respond to individual requests or emergencies, the mizusumashi operates according to planned cycles and established routines. This role enables the physical realization of pull-based replenishment by ensuring that materials are delivered consistently to production areas while empty containers, finished goods, or waste materials are removed in a structured manner.

From an operational perspective, the introduction of a *runner* reduces interruptions to production activities and limits unplanned material movements. By centralizing logistics tasks within a dedicated role, production operators can focus on value-adding activities, while material handling becomes a repeatable and predictable process. However, the effectiveness of the mizusumashi does not depend solely on the presence of a dedicated operator, but rather on the degree to which logistics activities are standardized and integrated within the broader production system.

A critical requirement for *runner*-based logistics systems is synchronization between material replenishment cycles and production rhythms. Synchronization ensures that deliveries occur at regular intervals aligned with actual consumption, preventing both material shortages and unnecessary accumulation of inventory. Without temporal alignment, even well-defined routes risk generating inefficiencies, as materials may arrive either too early or too late relative to production needs. Synchronization therefore represents the temporal dimension of flow control, linking logistics execution to production demand.

While synchronization addresses timing at the operational level, it must be supported by stability at the system level. This stability is achieved through production leveling, which aims to reduce fluctuations in production volume and mix over time. High variability in production demand introduces irregular material consumption patterns that undermine the effectiveness of standardized replenishment cycles. In such conditions, *runner*-based systems are forced to revert to reactive behavior, negating the benefits of flow-oriented logistics.

Production leveling reduces this variability by smoothing demand and creating more predictable consumption profiles. As a result, logistics activities can be planned with consistent workloads, fixed delivery frequencies, and stable route structures. The relationship between leveling and logistics is therefore reciprocal: leveled production enables stable logistics, while stable logistics supports sustained production performance.

Together, mizusumashi, synchronization, and production leveling form an integrated approach to flow stabilization. The mizusumashi provides the operational execution of material flow, synchronization ensures temporal alignment with production needs, and leveling establishes the systemic stability required to sustain standardized logistics processes. Treating these elements in isolation would limit their effectiveness; their value emerges from their combined application within a coherent flow-oriented system.

In summary, *runner*-based replenishment systems are not merely organizational solutions to material handling, but integral components of flow stabilization in Lean-oriented internal logistics. By addressing execution, timing, and variability simultaneously, these systems create the conditions for reliable material supply and predictable logistics performance. This stabilized environment represents a necessary foundation for the implementation of pull-based production planning and structured milk-run systems, which are examined in the following sections.

1.3.4 Pull Production Planning versus Push Production Planning

The effectiveness of flow-oriented internal logistics systems is strongly influenced by the planning logic governing production and material replenishment. In this context, the distinction between push-based and pull-based planning represents a fundamental difference in how production systems respond to demand and manage variability. These two approaches reflect contrasting assumptions regarding control, predictability, and the role of inventory within manufacturing systems.

Push-based planning systems are typically driven by forecasts and centralized scheduling. Production orders and material replenishment decisions are released upstream based on expected demand, with the objective of maximizing resource utilization and ensuring material availability. While this approach may appear effective in stable environments, it often generates mismatches between planned activities and actual consumption. Forecast inaccuracies, demand fluctuations, and process variability tend to propagate through the system, resulting in excess inventory, frequent rescheduling, and reactive logistics behavior.

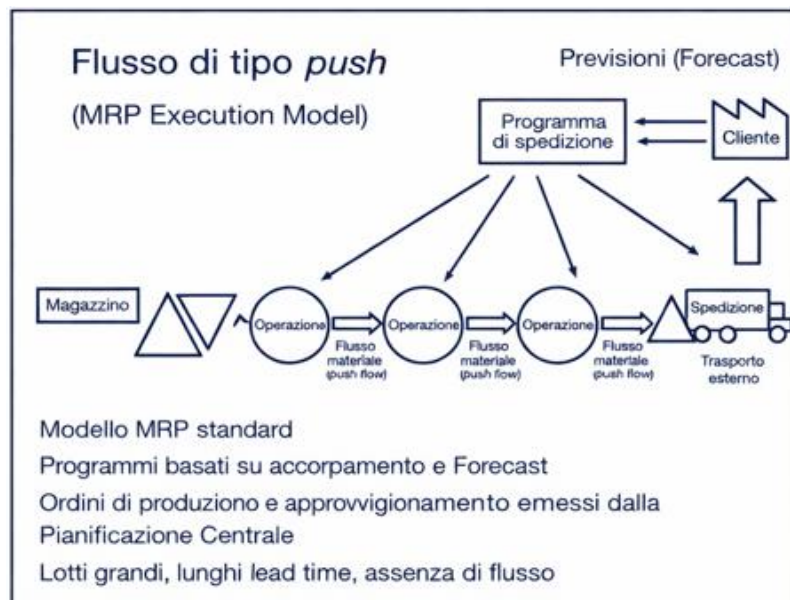


Figure 1.3 – Push-based planning system [1]

From an internal logistics perspective, push-based planning often leads to unstructured material flows. Materials are produced and moved according to plan rather than actual need, increasing the likelihood of congestion, storage constraints, and unnecessary handling. In such systems, logistics activities are frequently required to respond to urgent requests or expedite deliveries, undermining the predictability and stability of material handling operations.

In contrast, pull-based production planning aligns production and logistics activities with real consumption. Rather than releasing orders based on forecasts, pull systems authorize production and replenishment only when downstream demand is detected. This approach limits overproduction and reduces the accumulation of unnecessary inventory, enabling material flow to be more closely synchronized with production needs.

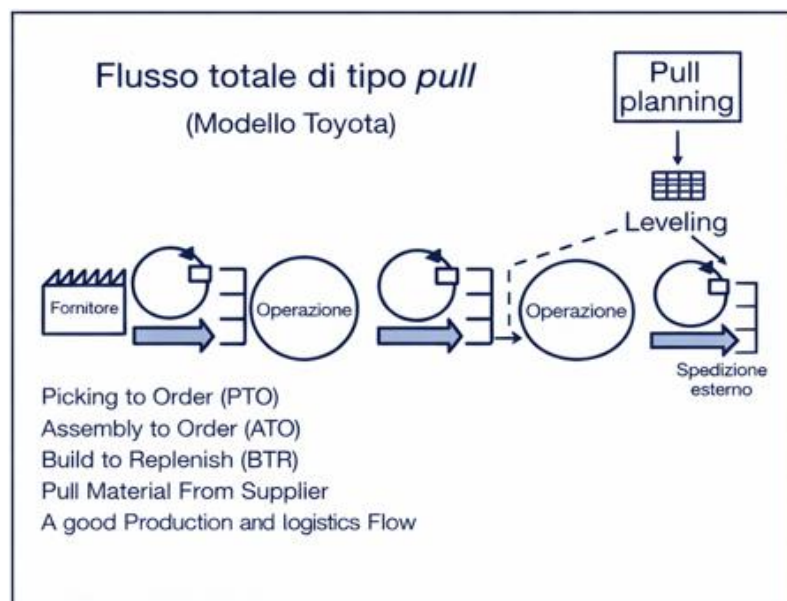


Figure 1.4 – Pull-based planning system [1]

Within a pull-based framework, internal logistics plays a central role in translating consumption signals into structured replenishment actions. Supermarkets, standardized replenishment routes, and *runner*-based logistics systems function as control mechanisms that regulate material flow without requiring detailed centralized scheduling. By responding to actual usage, logistics activities become more predictable and easier to integrate with production rhythms.

The transition from push to pull planning is closely linked to the concepts of synchronization and production leveling discussed in the previous section. Pull systems rely on stable and repeatable consumption patterns to function effectively. When production demand is highly variable or unbalanced, pull signals become irregular, increasing the risk of shortages or inefficiencies. For this reason, pull-based planning must be supported by leveled production and standardized processes to ensure reliability.

From a system perspective, pull planning shifts the focus of control from resource utilization to flow continuity. Performance is no longer evaluated primarily through output volume or machine efficiency, but through the ability of the system to deliver materials and products at the right time, in the right quantity, and with minimal waste. This shift reinforces the role of internal logistics as an integral component of production planning rather than a reactive support function.

It is important to note that pull-based systems do not eliminate the need for planning, but rather redefine its scope and function. Strategic planning remains necessary to define capacity, product mix, and long-term objectives. However, day-to-day execution is governed by consumption-driven signals, allowing the system to adapt more effectively to real operating conditions.

In summary, the distinction between push-based and pull-based planning represents a fundamental shift in how production and logistics systems are managed. Push systems prioritize forecast-driven control and resource utilization, often at the expense of flow stability. Pull systems, by contrast, align production and material replenishment with actual demand, supporting predictable logistics operations and waste reduction. This planning logic provides the foundation for structured internal transport solutions, such as milk-run systems, which are examined in the following section.

1.3.5 Milk-Run Systems in Internal Logistics

Milk-run systems represent a structured approach to internal material transportation designed to support flow-oriented logistics and pull-based production environments. Rather than responding to individual material requests, milk-run systems organize internal transport activities along predefined routes and fixed schedules, serving multiple pickup and delivery points within a single cycle. This approach enables a more efficient and predictable use of material handling resources while supporting stable material flows [8].

In traditional internal transport systems, material movements are often fragmented and demand-driven, with transport activities initiated in response to localized needs. Such an approach tends to generate redundant trips, uneven workload distribution, and high variability in logistics operations. Milk-run systems address these limitations by consolidating material movements and standardizing transport routes, thereby reducing unnecessary travel distances and improving overall transport efficiency.

From a Lean perspective, the primary value of milk-run systems lies in their ability to transform internal transportation from a reactive activity into a planned and repeatable process. By operating on fixed cycles, milk-runs introduce regularity into material flows, enabling logistics activities to be synchronized with production demand. This regularity supports flow continuity and reduces the likelihood of disruptions caused by unplanned material shortages or congestion in transport pathways.

Milk-run systems are closely linked to pull-based planning principles. Transport activities are triggered by actual material consumption rather than forecasted demand, often through the interaction with supermarkets and standardized replenishment signals. In this configuration, the milk-run functions as the physical execution layer of pull logistics, translating consumption signals into coordinated transport actions across the production system.

The effectiveness of milk-run systems depends strongly on prior flow stabilization. Standardized container sizes, clearly defined loading and unloading points, and consistent replenishment frequencies are essential prerequisites. Without these conditions, milk-run routes risk becoming inflexible or overloaded, leading to inefficiencies and the reintroduction of reactive transport behaviors. For this reason, milk-run systems are typically implemented after the introduction of supermarkets, *runner*-based replenishment, and synchronized production rhythms.

Another important advantage of milk-run systems is their contribution to workload balancing within internal logistics. By distributing transport activities evenly over time, milk-runs reduce peak workloads and improve the utilization of material handling equipment and personnel. This balancing effect enhances operational stability and simplifies logistics planning, particularly in complex manufacturing environments characterized by high product variety and frequent material movements.

From an organizational standpoint, milk-run systems support clearer role definition and responsibility allocation within internal logistics. Transport tasks are no longer dispersed across multiple operators or triggered by ad hoc requests, but are instead centralized within a structured logistics process. This clarity improves coordination between production and logistics functions and reduces the likelihood of interruptions at production workstations.

In addition, milk-run systems provide a scalable foundation for future improvements. Once routes, schedules, and material flows are stabilized, milk-runs can be supported by semi-automated or automated transport solutions. Consistent with Lean principles, such technological enhancements are most effective when applied to already standardized and waste-reduced processes, rather than as substitutes for process design.

In summary, milk-run systems represent an advanced stage of flow-oriented internal logistics, integrating standardized transport routes, pull-based replenishment, and synchronized execution. By consolidating material movements and stabilizing transport activities, milk-runs contribute to predictable logistics performance and reduced waste. These characteristics make milk-run systems a key enabler of efficient internal logistics and provide a natural link to the introduction of automation solutions, which are discussed in the following section.

1.3.6 Introduction to Automation in Internal Logistics

The increasing adoption of automation technologies in manufacturing has significantly influenced the design and management of internal logistics systems. Automated solutions are often introduced with the objective of improving efficiency, reducing labor-intensive activities, and enhancing process reliability. However, within a Lean and flow-oriented perspective, automation is not regarded as a primary driver of improvement, but rather as a potential enabler that must be carefully integrated into a stable and well-structured logistics system.

In traditional manufacturing environments, automation is frequently applied as a response to operational inefficiencies or capacity constraints. When introduced without a clear understanding of material flows and process variability, automated systems risk reinforcing existing problems rather than resolving them. In such cases, automation may increase system rigidity, reduce flexibility, and amplify the impact of poorly designed logistics processes.

Lean-oriented internal logistics approaches adopt a fundamentally different stance. Automation is considered appropriate only after material flows have been clearly defined, stabilized, and standardized. Concepts such as flow-oriented supply, supermarket-based inventory control, *runner*-based replenishment, and milk-run systems provide the structural foundation required for effective automation. When these elements are in place, automation can support logistics operations by executing repetitive and standardized tasks with high consistency and reliability.

Within internal logistics, automation solutions typically focus on material transportation and handling activities. Technologies such as automated guided vehicles (AGVs), autonomous mobile robots (AMRs), and automated conveyor systems are designed to perform predefined transport tasks along established routes. Their effectiveness depends strongly on the predictability of demand, the clarity of loading and unloading points, and the stability of replenishment cycles. Without these conditions, automated systems may experience frequent interruptions or require extensive manual intervention [9].

From a flow management perspective, automation offers potential benefits in terms of workload balancing and operational continuity. Automated transport systems can operate at consistent speeds, follow fixed schedules, and reduce variability associated with manual handling. This consistency supports synchronization with production rhythms and contributes to the overall stability of internal logistics flows. However, these benefits are realized only when automation is aligned with pull-based planning and leveled production conditions.

Another important consideration concerns the interaction between automated systems and human operators. Lean principles emphasize that automation should support, rather than replace, human decision-making. By delegating repetitive and non-value-added transport tasks to automated systems, human resources can be reassigned to activities that require flexibility, problem-solving, and continuous improvement. This approach reinforces the role of automation as a complement to human work rather than a substitute.

It is therefore essential to view automation within internal logistics as part of a broader system design process. Decisions regarding automation should be guided by an analysis of material flows, variability sources, and process stability, rather than by technological availability alone. Introducing automation without first addressing these elements may lead to suboptimal performance and limited long-term benefits.

In summary, automation represents a potential enabler of efficient internal logistics when applied within a structured and stabilized flow-oriented system. Lean-oriented approaches emphasize that automation should follow, not precede, the design of standardized material flows and replenishment processes. By integrating automation as a support to established logistics structures, manufacturing systems can enhance reliability and continuity while preserving the flexibility required for continuous improvement.

1.4 Lean Tools

This section presents the Lean tools adopted as methodological support for the analysis and improvement of internal logistics processes discussed in this thesis. The purpose of this section is not to apply these tools to a specific case, but to introduce their theoretical foundations and scope of use, providing a common reference framework for the subsequent case study.

1.4.1 The 5S System

The 5S system is a structured methodology aimed at establishing and maintaining orderly, standardized, and visually controlled work environments. Originating from the Toyota Production System, 5S is often regarded as a foundational Lean practice, as it creates the basic conditions required for process stability and continuous improvement. Although frequently associated with workplace organization, its implications extend beyond cleanliness, directly influencing efficiency, safety, and logistics performance.



Figure 1.5 – 5S system principles

The first step, Sort (Seiri), focuses on distinguishing between necessary and unnecessary items within a given work area. In logistics and material handling contexts, this phase involves identifying obsolete materials, excess containers, unused tools, and redundant equipment that occupy valuable space. By removing non-essential items, Sort reduces clutter and frees up floor space, which is particularly critical in environments where material flow and accessibility are key performance factors. This phase also contributes to making abnormalities more visible, as unnecessary accumulation of materials is no longer masked by general disorder.

The second step, Set in Order (Seiton), aims to define clear and logical locations for all remaining items. Materials, containers, tools, and handling equipment are positioned according to frequency of use and proximity to the point of application. In internal logistics, Set in Order supports shorter handling distances, faster material retrieval, and reduced motion waste. Visual identification of storage locations, standardized container placement, and clearly marked transport paths enable logistics activities to be performed consistently, regardless of operator experience.

The third step, Shine (Seiso), involves regular cleaning and inspection of work areas, equipment, and handling devices. Beyond its housekeeping function, Shine serves as a preventive control mechanism. In logistics environments, routine inspection of forklifts, carts, racks, and transport routes allows early detection of wear, damage, or unsafe conditions that could disrupt material flow. Clean and well-maintained environments also facilitate visual management, as deviations from normal conditions become immediately apparent.

The fourth step, Standardize (Seiketsu), consolidates the first three phases by defining standard procedures, visual controls, and operating rules. Standardization ensures that organization and cleanliness are not dependent on individual behavior but are embedded in daily operations. From a logistics perspective, this includes standardized storage layouts, container types, labeling systems, and replenishment rules. Standardized conditions provide a stable baseline that supports predictable material handling and enables meaningful performance comparison over time.

The fifth and final step, Sustain (Shitsuke), focuses on maintaining discipline and ensuring long-term adherence to established standards. Sustain is often considered the most challenging phase, as it requires consistent management commitment and employee involvement. In logistics-intensive environments, sustaining 5S is essential to prevent gradual degradation of material organization, which can quickly lead to increased search times, unplanned movements, and safety risks. Regular audits, training activities, and visual performance indicators are commonly used to support this phase.

From a system perspective, the 5S methodology plays a critical role in enabling higher-level Lean practices. Organized and standardized environments are prerequisites for effective supermarket management, *runner*-based replenishment, milk-run systems, and automation.

Without the stability provided by 5S, advanced logistics solutions are difficult to implement and sustain, as variability in workplace conditions undermines process reliability.

In summary, the 5S system provides a structured approach to organizing work environments that directly supports efficient internal logistics and material handling. By reducing clutter, standardizing locations, and promoting visual control, 5S minimizes waste related to motion, waiting, and space utilization. Its role as a foundational Lean tool makes it a necessary starting point for the application of more advanced flow-oriented logistics and continuous improvement initiatives discussed in the subsequent sections.

1.4.2 Value Stream Mapping

Value Stream Mapping (VSM) is a Lean tool used to visualize, analyze, and improve the flow of materials and information required to deliver a product or service to the customer. Unlike traditional process mapping techniques, which often focus on individual operations or departments, VSM adopts a system-wide perspective, emphasizing the interactions and dependencies between activities along the entire value stream [10].

The primary objective of VSM is to distinguish between value-adding and non-value-adding activities and to identify sources of waste that disrupt flow continuity. By representing both material and information flows on a single map, VSM highlights how production, logistics, and planning activities interact, making inefficiencies visible at a systemic level rather than in isolated processes. This holistic view is particularly relevant in complex manufacturing environments, where performance losses often arise at process interfaces.

A key characteristic of Value Stream Mapping is the distinction between the current state and the future state of the system. The current state map provides a structured representation of how the system actually operates, capturing process sequence, inventory levels, lead times, and information flows. This representation serves as a factual baseline for analysis, avoiding assumptions and enabling objective evaluation of system performance.

The future state map, by contrast, represents a conceptual model of how the value stream should operate once improvement actions are implemented. It is not intended as a detailed implementation plan, but rather as a directional guide that defines target conditions such as reduced lead time, improved flow continuity, and clearer synchronization between production and logistics. The gap between current and future state maps forms the basis for structured improvement initiatives.

From an internal logistics perspective, VSM is particularly effective in identifying inefficiencies related to material handling, inventory accumulation, and coordination between logistics and production. Excessive buffers, unbalanced flows, and delays in material replenishment often become evident when mapped alongside production activities. In this

sense, VSM supports the analysis of internal logistics not as a standalone function, but as an integral component of the production system.

An important strength of VSM lies in its ability to support decision-making at the system level. By visualizing lead times and flow interruptions across the entire value stream, VSM helps prevent local optimizations that may improve individual processes while degrading overall performance. This characteristic aligns closely with Lean Manufacturing and Total Flow Management principles, which emphasize system-wide optimization over isolated efficiency gains.

However, the effectiveness of Value Stream Mapping depends strongly on the way it is applied. VSM should be grounded in direct observation of processes and accurate data collection, rather than on theoretical or idealized representations. When used without a clear understanding of system dynamics, VSM risks becoming a descriptive exercise rather than a driver of meaningful improvement.

Furthermore, VSM does not replace detailed analysis tools but complements them. While it provides a macro-level view of flows and interactions, it must often be supported by more focused tools—such as spaghetti charts or time studies—to analyze specific inefficiencies in greater detail. In this sense, VSM functions as a guiding framework that helps prioritize improvement efforts rather than as a standalone solution.

In summary, Value Stream Mapping is a powerful analytical tool for understanding and improving the flow of materials and information within manufacturing systems. By adopting a holistic perspective and distinguishing between current and desired system states, VSM supports structured improvement initiatives aimed at waste reduction and flow optimization.

1.4.3 Spaghetti Chart

The spaghetti chart is a Lean analysis tool used to examine the physical movement of operators, materials, or equipment within a defined workspace. Its primary purpose is to analyze how spatial layout and process organization influence movement patterns, with particular attention to identifying inefficiencies related to transportation and motion.

Unlike tools that focus on process logic or information flow, the spaghetti chart is explicitly concerned with the spatial dimension of operations. Actual movement paths are recorded directly on a layout representation, capturing how activities are performed in real operating conditions rather than how they are intended to be performed. This characteristic makes the tool especially effective in highlighting discrepancies between standardized processes and daily practice.

In internal logistics contexts, the spaghetti chart is commonly applied to analyze material handling activities such as line feeding, replenishment routes, and transport operations performed by logistics personnel. Long travel distances, frequent backtracking, and intersecting

paths often indicate poor coordination between storage locations and production areas, as well as suboptimal layout design. By making these patterns visible, the spaghetti chart supports objective evaluation of logistics-related waste.

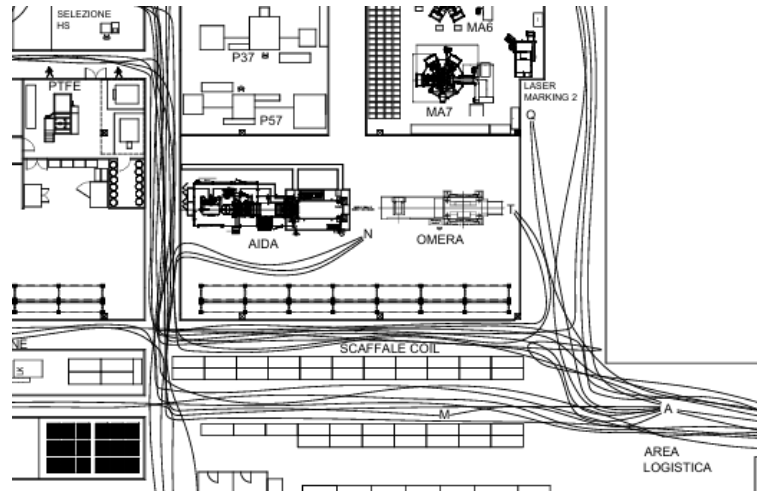


Figure 1.6 – Real example of a spaghetti chart

One of the main strengths of the spaghetti chart lies in its ability to support layout and flow redesign decisions. By quantifying distances traveled and visualizing movement concentration areas, the tool enables the identification of opportunities to simplify routes, shorten transport paths, and reduce unnecessary handling. These insights are particularly valuable when evaluating alternative layout configurations or reorganizing storage and replenishment areas.

The spaghetti chart is typically used as a complementary tool within a broader analysis framework. While Value Stream Mapping provides a macro-level overview of material and information flows, the spaghetti chart offers a focused analysis of physical movement at the operational level. Together, these tools allow inefficiencies to be addressed both from a systemic and a spatial perspective.

It is important to note that the effectiveness of the spaghetti chart depends on accurate data collection and a clearly defined scope of analysis. Observations must be conducted over representative time periods and within a well-defined layout context to ensure meaningful results. When applied systematically, the spaghetti chart provides a robust basis for identifying and prioritizing improvement actions related to internal logistics and material handling.

In summary, the spaghetti chart is a practical and effective tool for analyzing physical movement within manufacturing environments. By revealing motion and transportation inefficiencies linked to layout and logistics organization, it supports data-driven decisions aimed at improving flow efficiency and reducing waste. Within this thesis, the spaghetti chart is used as a key methodological tool to support the analysis and redesign of internal logistics processes in the case study.

2 Company Overview: Tenneco Inc.

Tenneco is a leading global Tier-1 supplier operating within the automotive and broader transportation industries. The company designs, manufactures, and distributes a wide range of components and systems for original equipment manufacturers (OEMs) as well as for the aftermarket. Tenneco operates on a global scale, supporting major automotive customers through an extensive manufacturing, engineering, and distribution footprint.

In the most recent [11] overview (November 2025), Tenneco employs approximately 60,000 people worldwide and operates 184 manufacturing plants, 23–24 distribution centers, and nearly 40 engineering and technical facilities across 28 countries. This global presence enables the company to serve geographically dispersed customers while maintaining proximity to key automotive production hubs.

The business of Tenneco is structured around several main operating segments, each addressing specific technological and market needs within the automotive sector. These include Clean Air, Powertrain, Champion Ignition, Performance Solutions, and DRiV, the company's aftermarket division. Across these segments, Tenneco provides products such as emission control systems, engine components, braking systems, suspension technologies, ignition systems, and aftermarket solutions. This diversified portfolio allows the company to operate across multiple mobility segments, including passenger vehicles, commercial vehicles, off-highway equipment, and selected industrial applications, reducing dependency on a single end market.

From a strategic perspective, Tenneco positions itself as a technology-driven organization with a strong focus on operational excellence. The company has defined a standardized global operating system, internally known as P3 (People, Performance, Pride), which establishes common performance standards, safety requirements, and continuous improvement practices across all plants worldwide. This operating model promotes process discipline, standardized workflows, and measurable performance indicators, providing a structured framework for deploying improvement initiatives consistently across the organization.



Figure 2.1 – Company Logo

2.1 The Main Business Groups of Tenneco

Tenneco structures its global operations around five main business groups, each addressing specific technological domains and market segments within the automotive industry. This organizational structure allows the company to manage a diversified product portfolio while maintaining a focus on operational excellence and customer-specific requirements [11].

	Clean Air	Powertrain	Champion Ignition	Performance Solutions	DRIV™
Description	Engine emission control and acoustic performance	Engine components for improved efficiency and durability	High-performance ignition systems known for reliability and durability in demanding environments	Products and systems designed to optimize ride experience	Aftermarket business with a broad "House of Brands"
Brands		   		   	       

Figure 2.2 – Company main business groups

2.1.1 Clean Air

As a global leader in emission control solutions, Tenneco designs, engineers, and manufactures advanced systems for the transportation sector, serving passenger vehicles, commercial vehicles, and off-highway applications. The company develops technologies aimed at improving fuel efficiency, reducing exhaust emissions, and optimizing acoustic performance, while ensuring compliance with increasingly stringent international regulations.

Within a global context characterized by continuously evolving emissions standards and growing demand for vehicle efficiency, Tenneco's Clean Air division plays a strategic role in supporting the transition toward more sustainable mobility solutions. Rather than focusing solely on regulatory compliance, the division pursues high-performance engineering solutions that integrate environmental responsibility with operational efficiency and long-term durability.

The engineering activities of the Clean Air division are structured around three core technological domains, which together address regulatory, efficiency, and acoustic requirements. The first domain concerns exhaust after-treatment systems, through which Tenneco supports global engine manufacturers in complying with regulations such as Euro 6d, Euro 7, China 6, and Bharat Stage VI. These systems rely on advanced catalytic and filtration technologies to significantly reduce harmful emissions while preserving engine performance and reliability.

The second domain focuses on energy recovery technologies, aimed at enhancing overall vehicle efficiency by converting waste energy generated during engine operation into usable energy. By recovering energy that would otherwise be dissipated, these solutions contribute to reduced fuel consumption and lower emissions, aligning efficiency improvements with environmental objectives.

The third domain involves sound engineering, where exhaust systems are designed to balance effective noise reduction with brand-specific acoustic characteristics. Rather than simply minimizing sound levels, these systems deliver controlled and distinctive acoustic signatures that support vehicle differentiation, while ensuring compliance with noise regulations and customer expectations.

Overall, these three technological domains illustrate how Tenneco's Clean Air division integrates emissions control, efficiency enhancement, and acoustic performance within a unified engineering approach, supporting the broader objectives of sustainable, high-performance mobility.

2.1.2 Powertrain

Tenneco's Powertrain division is focused on the development and production of advanced engine components and technologies designed to support innovation in modern powertrain systems. The division provides original equipment solutions to global automotive manufacturers, addressing the technical challenges posed by increasingly stringent regulations and evolving market requirements.

Powertrain engineering activities are centered on the design, development, and manufacturing of components that enable engine designers to improve efficiency, durability, and emissions performance while maintaining high levels of reliability. In this context, the division supports a wide range of powertrain architectures and operating conditions, contributing to the optimization of engine performance across diverse applications.

A key characteristic of Tenneco's Powertrain portfolio is its compatibility with multiple fuel technologies, including gasoline, diesel, alternative fuels, and hybrid systems. Advanced engine components and specialized surface coatings play a significant role in reducing friction losses, improving thermal efficiency, and lowering exhaust emissions. These technologies support compliance with global regulatory standards while enabling further advancements in engine design and performance.

Overall, the Powertrain division contributes to Tenneco's strategic objective of delivering high-performance, regulation-compliant engine solutions, reinforcing the company's position as a reliable technology partner within the automotive supply chain.

2.1.3 Performance Solutions

Tenneco's Performance Solutions division encompasses a portfolio of specialized companies engaged in the development of advanced systems in collaboration with leading global manufacturers. The division focuses on the design, engineering, and implementation of technologies aimed at improving vehicle safety, operational performance, and user experience across a wide range of mobility applications.

Performance Solutions supports multiple sectors, including passenger vehicles, heavy-duty and off-highway machinery, industrial equipment, rail systems, and selected aerospace applications. Within this context, the Original Equipment activities of the division involve close collaboration with automotive and industrial manufacturers to enhance vehicle dynamics, control, and ride performance. Engineering efforts are directed toward meeting stringent industry standards related to operational reliability, passenger comfort, and safety performance.

A key objective of the division is to advance mobility systems by extending the functional limits of traditional vehicle dynamics solutions. Through innovative engineering approaches, Performance Solutions contributes to improved handling, braking performance, and overall system stability, addressing both performance expectations and regulatory requirements.

In addition to vehicle dynamics technologies, the division includes Protective Systems activities focused on safeguarding critical components from thermal stress, mechanical wear, and electromagnetic interference. These solutions are designed to enhance durability and reliability in demanding operating environments, where component protection is essential for maintaining consistent performance over time.

Overall, the Performance Solutions division plays a strategic role within Tenneco by delivering integrated technologies that support safety, performance, and reliability across diverse mobility sectors, reinforcing the company's position as a key technology partner in advanced transportation systems.

2.1.4 DRiV

The DRiV division operates through a global network of more than thirty established aftermarket automotive brands, widely recognized for their reliability and long-standing presence within the industry. Through this portfolio, Tenneco supplies a broad range of replacement parts and systems designed to support vehicle performance, durability, and safety throughout the product lifecycle.

DRiV's activities are focused on delivering high-quality aftermarket solutions capable of meeting diverse operating conditions, including demanding road environments, long-distance usage, and everyday driving scenarios. The division addresses the needs of a wide range of vehicle platforms, supporting both passenger and commercial applications, and placing strong emphasis on product consistency and functional reliability.

Within Tenneco's overall corporate structure, the DRiV division plays a strategic role by strengthening the company's position in the global automotive aftermarket. By combining an extensive brand portfolio with standardized quality and operational practices, DRiV contributes to the objective of providing dependable aftermarket solutions while maintaining high levels of performance, reliability, and customer trust.

2.1.5 Champion Ignition

Champion Ignition represents one of Tenneco's most established brands within the ignition systems segment, with a long-standing presence in both original equipment and aftermarket applications. The brand is primarily focused on the design and production of ignition components, including spark plugs, glow plugs, ignition coils, and related electronic systems, which play a critical role in engine performance and reliability.

From a functional perspective, ignition systems are responsible for initiating and controlling the combustion process within internal combustion engines. The performance of these components directly influences engine efficiency, fuel consumption, emissions, and cold-start behavior. For this reason, Champion's product portfolio is developed to ensure consistent ignition performance under a wide range of operating conditions, including high temperatures, variable loads, and demanding duty cycles.

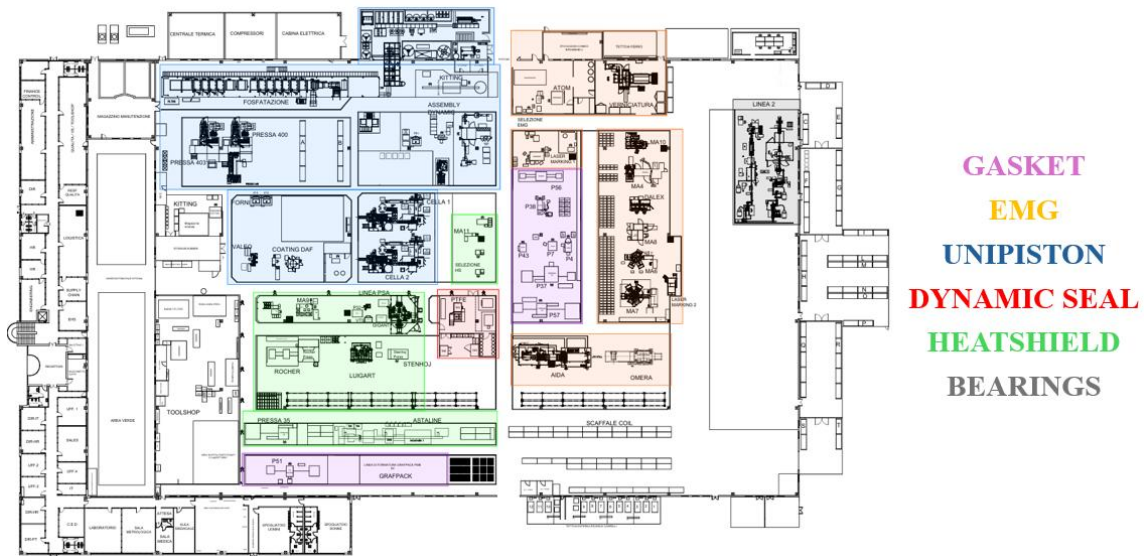
The engineering activities associated with Champion Ignition are centered on material selection, thermal resistance, and electrical performance. Advanced electrode materials and coatings are used to enhance durability and reduce wear over time, while optimized geometries contribute to improved spark stability and combustion efficiency. These design choices support the broader objective of achieving reliable engine operation while complying with increasingly stringent emission standards.

In addition to traditional internal combustion applications, Champion Ignition technologies are continuously adapted to evolving powertrain architectures, including hybrid systems, where ignition performance remains a critical factor for engine operation during intermittent cycles.

Within Tenneco's overall structure, Champion Ignition complements the company's portfolio by providing essential components for engine functionality, reinforcing its position across both OEM and aftermarket channels. The integration of ignition technologies with broader powertrain and aftermarket solutions allows Tenneco to offer a more complete and coherent product range, aligned with the technical and operational requirements of modern mobility systems.

2.2 Chivasso Plant Overview

The Tenneco plant located in Chivasso (Turin, Italy), where the thesis project was carried out, operates within the Powertrain Business Group. The facility is organized into several production departments, each specialized in a specific manufacturing cycle and product family. This structure reflects the need to manage heterogeneous sealing technologies while maintaining process specialization, quality control, and production efficiency.



2.2.1 Gasket

The Gasket department is dedicated to the production of static steel seals. These components are primarily used to ensure tightness between fixed mechanical interfaces, preventing fluid leakage and maintaining pressure integrity in engine assemblies. Static gaskets play a critical role in engine reliability, as their performance directly affects sealing efficiency under thermal and mechanical loads.



2.2.2 EMG

The EMG department, an acronym for Elastomeric Metal Gaskets, focuses on the production of composite seals that combine metal substrates with elastomeric materials and fibers. This hybrid structure allows EMG components to merge the mechanical strength of metal with the flexibility and elasticity of rubber-based materials. From a functional perspective, elastomeric metal gaskets are particularly suited for applications requiring both dimensional stability and adaptability to surface irregularities.



Figure 2.5 – Example of finished product of EMG

2.2.3 Unipiston

The Unipiston department specializes in the production of seals for automatic transmission systems, commonly referred to as lip seals or sealing rings. These components are designed to seal rotating mechanical elements such as shafts and gears, preventing lubricant leakage while protecting the system from external contaminants. A distinguishing feature of the seals produced in this department is the use of high-modulus elastomers, which increase contact pressure and enhance sealing performance under dynamic operating conditions.



Figure 2.6 – Example of finished product of Unipiston

2.2.4 Dynamic Seal

The Dynamic Seal department produces seals designed for applications involving relative motion between components, such as rotating crankshafts or sliding assemblies. These seals are typically manufactured using elastomeric materials and polytetrafluoroethylene (PTFE), selected for their resistance to wear, temperature variations, pressure, and chemical exposure. Dynamic sealing solutions are critical in powertrain applications, where continuous motion and harsh operating environments impose stringent performance requirements.



Figure 2.7 – Example of finished product of Dynamic Seal

2.2.5 Heat Shield (HS)

The Heat Shield (HS) department is responsible for the production of thermal protection components for engine systems. Heat shields are used to limit heat transfer from high-temperature engine parts to surrounding components and vehicle body structures. These products are generally composed of aluminum or steel layers combined with insulating materials, such as fiberglass, enabling effective thermal management and contributing to component durability and vehicle safety.



Figure 2.8 – Example of finished product of Heat Shield

2.2.6 Bearing

The Bearing department is dedicated to the production of bearing components used in engine and powertrain applications. These components are designed to support rotating elements, reduce friction between moving parts, and ensure proper load distribution during operation.

The manufacturing process typically involves forming, machining, and surface finishing operations, with particular attention to dimensional accuracy and surface quality. Given the precision required, production in this department is characterized by tight tolerances and strict quality control procedures.



Figure 2.9 – Example of finished product of Bearing

3 Case study and Initial state Analysis

3.1 Plant Context

This chapter introduces the operational environment in which the improvement activities developed in this thesis were carried out. The case study was conducted at the Tenneco plant located in Chivasso (Turin, Italy), belonging to the Powertrain Business Group. The facility operates within a typical automotive supply chain context, characterized by high product variety, strict quality requirements, and demanding delivery schedules imposed by OEM customers [12], [13].

The plant specializes in the production of sealing systems and thermal protection components for powertrain applications. The manufacturing organization is structured into dedicated departments, each associated with specific product families and process technologies. This configuration, while necessary to ensure process specialization and product quality, results in a distributed production layout where materials must frequently move between storage areas and multiple production departments.

From a logistical standpoint, the plant presents a relevant case for analysis due to the significant volume of internal material handling activities required to sustain production continuity. Raw materials, semi-finished components, and finished goods are continuously transferred across different areas of the facility. These flows are managed through internal logistics resources responsible for supplying workstations, transferring intermediate products, and supporting shipping operations.

The coexistence of multiple product technologies and spatially separated departments generates complex internal material flows. In such an environment, the effectiveness of warehouse organization and transport activities directly influences production stability and overall operational performance. Inefficiencies in material handling can rapidly propagate to production processes, resulting in delays, excess movements, and reduced resource utilization.

For these reasons, the Chivasso plant represents an appropriate context for analyzing internal logistics organization and evaluating structured improvement actions aimed at enhancing flow efficiency and operational stability. The following sections examine the current state of internal logistics processes, identifying critical issues that form the basis for the improvement initiatives developed in the subsequent chapters [13].

3.2 Description of the initial Internal Logistics System

The internal logistics system currently adopted at the Chivasso plant is primarily based on manual material handling activities performed by dedicated personnel.

The responsibility for ensuring material availability at production workstations is assigned to a logistics operator, commonly referred to as the *runner*, whose role consists of supplying raw materials, transferring semi-finished products between departments, and transporting finished goods to the designated shipping area.

Material replenishment is not governed by a formally structured or time-based schedule. This type of reactive material supply is typical of non-lean logistics systems and often leads to inefficiencies in transport and handling activities [7]. Instead, logistics activities are mainly triggered by production needs, often communicated verbally or through direct requests from operators. As a result, material movements are largely reactive rather than planned according to predefined routes or standardized frequencies.

Raw materials are stored within internal warehouse areas and are retrieved by the *runner* when required by the production departments. Once materials are consumed at the workstation, replenishment is requested, and the *runner* proceeds to collect the necessary items from storage locations. Semi-finished products generated by one department and required by another are transported according to production progression, without a fixed circulation pattern. Similarly, finished goods are moved to the shipping area upon completion, depending on available capacity and operational priorities.

This operational configuration leads to a fragmented internal flow. Fragmented flows and lack of standardization are recognized as major sources of waste in internal logistics systems [7]. Transport activities are distributed throughout the shift without a defined sequence of stops or optimized routing logic. The *runner's* movements therefore depend on the order and urgency of requests received, generating variability in workload and travel distances. In the absence of standardized transport cycles, the same production areas may be visited multiple times within short time intervals, while others may experience longer waiting times.

From a warehouse management perspective, storage areas are not structured according to standardized organizational criteria. Raw materials and packaging materials are positioned without a defined logic based on frequency of use or proximity to the point of consumption. Instead, material placement largely depends on the operational decisions of the *runner* during each shift, without adherence to a formalized layout or replenishment strategy. As a result, component retrieval may require extended search times and unnecessary transport distances, leading to increased motion and handling inefficiencies within the plant.

The current system does not incorporate formal pull mechanisms or supermarket-based control logic. Inventory levels near production lines are determined by practical convenience and available space rather than by defined consumption-based limits. This approach increases the

risk of excess line-side stock while simultaneously failing to prevent occasional shortages caused by delayed replenishment.

Overall, the internal logistics system can be characterized as functional but not standardized. Material availability is generally maintained, and production interruptions are limited; however, the absence of structured routes, synchronized replenishment cycles, and flow-oriented planning results in inefficiencies related to motion, transportation, and workload imbalance. These characteristics make the current configuration suitable for a structured AS-IS analysis aimed at identifying opportunities for warehouse reorganization, route standardization, and flow stabilization.

3.3 Initial Warehouse configuration

The warehouse configuration at the Chivasso plant constitutes a critical component of the internal logistics system, as it directly affects material accessibility, transport distances, and overall flow continuity. Warehouse layout design plays a critical role in minimizing handling effort and improving flow efficiency within manufacturing systems [14]. The packaging storage areas consist primarily of shelving systems located within the main warehouse area (orange area in Figure 3.1), complemented by two additional shelving units (light blue area in Figure 3.1) that were introduced during the period under analysis and positioned closer to the production departments in order to facilitate faster access to frequently used components.

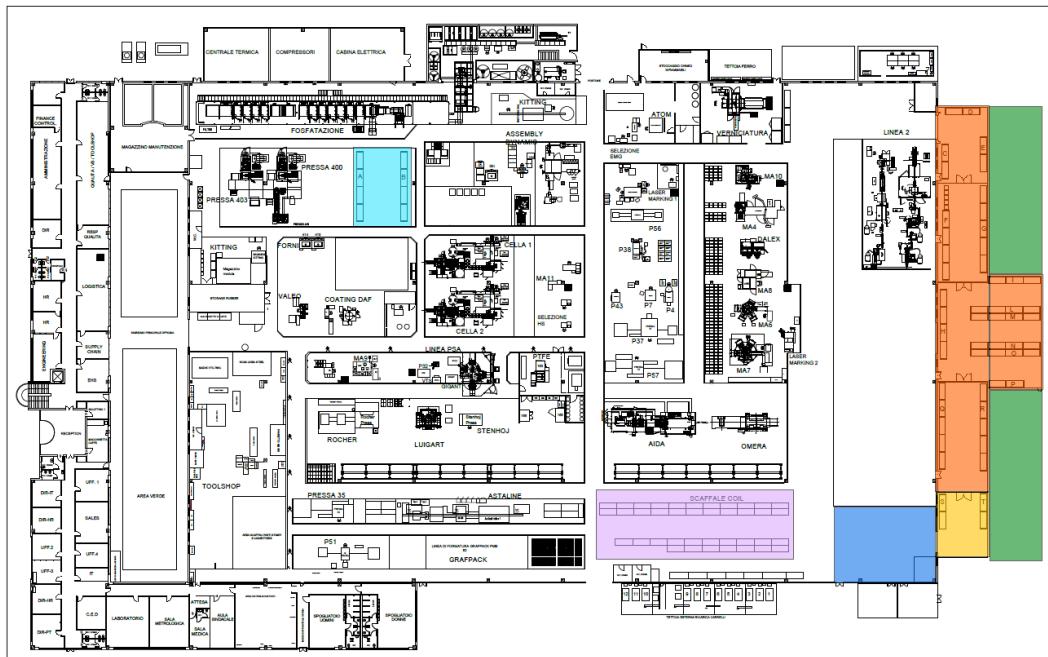


Figure 3.1 – Storage area

In addition to these shelving structures, the warehouse configuration includes a ground-level outbound area (blue area in Figure 3.1), where finished product pallets are assembled, wrapped, and temporarily stored prior to shipment. This area functions as the final consolidation point for outgoing goods and plays a key role in ensuring timely dispatch to customers. Conversely, a dedicated inbound ground-level area (yellow area in Figure 3.1) is used for the temporary deposition of incoming raw materials. This zone allows for rapid unloading of trucks, reducing vehicle waiting times and minimizing congestion at receiving docks. After unloading, materials are subsequently allocated to their respective storage locations within the warehouse.

Furthermore, an external storage area (green area in Figure 3.1) is designated for the temporary storage of customer-owned plastic containers, commonly referred to as KLT boxes. These containers are essential for packaging finished products according to customer specifications and are periodically cycled between the plant and customer facilities. Their external positioning adds an additional logistical interface that must be coordinated within the overall material flow.

Although these areas collectively ensure sufficient storage capacity to sustain production, the overall organization reflects a functional rather than flow-optimized design. Storage locations are assigned broadly by material category, yet the internal positioning of components within shelving areas does not consistently follow structured criteria based on consumption frequency, transport efficiency, or proximity to production lines.

3.3.1 Warehouse Layout and Storage Logic

The warehouse is composed of vertical shelving systems, palletized storage zones, and designated ground-level areas for inbound and outbound material handling. While macro-level separation between material categories exists, the internal allocation of components lacks a standardized logic aligned with flow-oriented principles.



Figure 3.2 – Warehouse

High-rotation materials are not systematically positioned closer to the most frequently supplied production departments. Instead, allocation decisions often depend on available space at the time of storage or on the operational judgment of the runner responsible for material handling during the shift. Since the plant operates on three shifts, different runners may adopt distinct placement approaches based on personal preference or convenience. This variability introduces inconsistency in storage configuration over time, making material retrieval less predictable and increasing the likelihood of extended search times or unnecessary transport movements.

The absence of clearly defined storage policies and standardized allocation rules generates cumulative inefficiencies. Materials that were originally positioned according to a certain logic may gradually shift within the warehouse depending on temporary constraints or individual working methods. As a result, internal transport routes become more complex, and the reproducibility of logistics operations decreases.

Visual management elements are present but limited in their ability to enforce standardized positioning. Labels and basic identification systems exist; however, the lack of structured zoning, frequency-based classification, or dedicated high-rotation areas reduces the effectiveness of the storage layout.

Transport pathways within the warehouse are shared between storage activities and material movements. In the absence of defined circulation routes optimized for cyclic replenishment, overlapping paths and minor congestion can occur, particularly during periods of high activity. This configuration further reinforces the reactive nature of material handling operations.

Overall, the layout reflects a traditional storage-oriented configuration that ensures functional continuity but does not fully support standardized internal logistics or minimized transport effort.

3.3.2 Material Categories and Storage Characteristics

The warehouse handles several distinct material categories, each characterized by specific logistical requirements and handling constraints.

Raw materials include metallic substrates, elastomeric compounds, semi-processed components, and auxiliary production materials. These items are typically stored on pallets or within shelving units and require controlled allocation to ensure traceability and production continuity. Their rotation frequency varies depending on product mix and daily production planning.

Semi-finished products are generated within individual departments and subsequently transferred to downstream processes. These intermediate components require temporary storage solutions that allow rapid retrieval while preventing excessive accumulation. Due to variability in production pacing, semi-finished materials may experience fluctuating storage durations, adding complexity to internal coordination.

Packaging materials comprise cartons, plastic inserts, protective films, and labeling elements required for final product preparation. These materials often occupy considerable physical volume relative to their weight and are frequently replenished. Their position within the warehouse, however, does not consistently reflect their high usage frequency, leading to additional handling movements during line supply operations.



Figure 3.3 – Example of packaging

Finished goods are assembled into pallets within the outbound area and temporarily stored pending shipment. This zone is more structured due to shipping documentation and dispatch requirements, yet its interaction with upstream production and internal transport remains dependent on manual coordination.

Finally, customer-owned KLT containers, stored in the external area, represent an additional logistical element requiring periodic retrieval and redistribution. Their location outside the main warehouse area introduces additional travel distances and necessitates coordination between internal logistics and external storage interfaces.

The coexistence of these heterogeneous material categories within a non-standardized storage configuration increases the operational complexity of internal logistics. Differences in size, handling method, rotation frequency, and storage requirements demand structured organization to support efficient and predictable material flows. In the absence of such structuring, material handling activities remain heavily dependent on operator experience and individual working practices.



Figure 3.4 – Initial storage for KLT

3.4 Analysis of Runner Activities

The internal material handling activities at the Chivasso plant are primarily managed by a dedicated logistics operator, commonly referred to as the runner. The runner is responsible for ensuring material availability across all production departments and for coordinating the physical movement of raw materials, semi-finished components, packaging materials, and finished goods within the facility.

Over time, the runner's role has progressively expanded. In addition to traditional material supply tasks, the runner has also been integrated into the outbound logistics process, supporting the completion and consolidation of finished product pallets prior to shipment. This integration increases the operational scope of the role and further concentrates logistics responsibilities on a single operator per shift.

During each shift, the runner performs multiple operational tasks, including:

- supplying raw materials from the warehouse to production lines,
- delivering packaging materials required for final product preparation,
- transferring semi-finished products between departments,
- transporting finished goods to the outbound consolidation area,
- supporting the completion and final preparation of finished product pallets,
- managing waste containers and disposing of production scrap.

The management of scrap containers represents a critical activity within the production environment. Several presses generate significant quantities of metallic offcuts during operation. If scrap bins are not emptied regularly and become full, production machines may

be forced to stop due to lack of disposal capacity. For this reason, scrap handling is not a secondary task but an essential activity to ensure uninterrupted production continuity.

At the beginning of each shift, the runner typically receives verbal instructions regarding the materials that need to be delivered to production. These instructions may concern raw materials, semi-finished components, or packaging elements required for specific orders. The absence of a formalized planning system means that priorities are communicated informally, often based on immediate production needs.

Although an initial set of tasks is usually defined at shift start, operational priorities frequently change during the day. Urgent customer orders, machine stoppages, or sudden material shortages can require immediate intervention. Consequently, the runner must continuously adapt activities in response to emerging conditions. This reactive environment often leads to interruptions of previously started tasks and, in some cases, to the repeated handling of the same material (double handling). While certain emergency situations cannot be entirely eliminated in a dynamic production context, their frequency and impact can be mitigated through more structured planning and standardized logistics routines.

The absence of a predefined transport route or fixed replenishment cycle results in highly variable movement patterns. The runner alternates between warehouse areas, production departments, inbound and outbound zones depending on urgency, generating irregular travel distances and workload fluctuations. Multiple visits to the same department within short time intervals are common, particularly when requests are received separately rather than consolidated.

The three-shift organization of the plant further contributes to variability. Each runner develops individual operational habits, including personal prioritization criteria and preferred storage locations. This lack of standardization reinforces inconsistencies in material allocation and retrieval logic, increasing dependence on operator experience rather than on structured process design.

Despite these inefficiencies, the system remains functionally capable of supporting production. However, the reliance on reactive decision-making, the concentration of diverse tasks on a single operator, and the absence of standardized routes limit the overall efficiency and predictability of internal logistics performance.

For these reasons, a structured analysis of runner movements was conducted in order to quantify travel distances, identify recurrent inefficiencies, and evaluate opportunities for route standardization and workload balancing. The following section presents the results of the movement analysis performed through the application of the spaghetti chart methodology.

3.5 Spaghetti Chart and Movement Analysis

In order to objectively evaluate the internal logistics configuration described in the previous sections, a structured movement analysis was conducted on runner activities using spaghetti chart methodology [15].

The objective of this analysis was to:

- map the real transport paths followed during the shift.
- identify recurring stops and high-frequency service areas.
- quantify variability in route patterns.
- detect inefficiencies related to transport, motion, and task interruption.

The runner is required to serve a large number of operational stations distributed across the plant. Each of these areas requires different types of interventions: material replenishment, scrap removal, pallet handling, WIP transfer, or finished goods transport. The absence of a predefined cyclic route means that these stops are not visited in a fixed sequence. Instead, they are accessed depending on perceived emergency, verbal calls, or visible accumulation of materials.

3.5.1 Observed Movement Patterns

From the shift observations and simulation, the following recurring patterns were identified:

- **High Route Fragmentation**
Movements are frequently interrupted by urgent calls (e.g., missing raw material at AIDA, emergency coating startup). The runner often begins one task and is redirected before completing the intended cycle.
- **Repeated Crossings of Central Corridor**
Many tasks require passing through the main corridor multiple times within short intervals, the runner could follow different path to check if there are some action that can be done.
- **Double Handling of Materials**
Due to lack of planning, some materials are moved more than once.
For example:
 - scrap bins replaced and later repositioned,
 - pallets temporarily stored due to lack of space in finished goods warehouse,
 - incomplete KLT pallets returned outside.
- **Task Overlap Between Production and Logistics**
In certain departments (e.g., EMG, Phosphatizing), operators temporarily perform logistics-related tasks when the runner is unavailable, potentially stopping production activities.

- Waiting and Equipment Constraints

Operational inefficiencies also derive from:

- insufficient maneuvering space near KLT canopy,
- limited battery autonomy of handling equipment,
- obstacles in corridors (pallets, scrap bins, packaging materials).

These elements contribute to a non-linear and highly variable movement pattern.

3.5.2 Scrap Handling as a Critical Constraint

Scrap management represents one of the most time-sensitive activities in the current logistics configuration. As highlighted in the operational notes, presses such as AIDA, OMERA, and Rocher generate significant volumes of metallic offcuts.

If scrap bins reach full capacity, presses risk being stopped. For this reason, scrap removal often takes priority over planned material replenishment activities.

However, scrap handling is currently not organized through fixed frequency cycles. Instead, the runner checks bins visually or reacts when operators report full containers. This reactive approach increases variability in workload and contributes to unbalanced route distribution.

3.5.3 Variability Between Shifts

The analysis conducted across multiple shifts revealed differences in:

- starting conditions of production lines,
- preparation of materials from previous shift,
- level of organization of finished goods area,
- consistency in applying standard flow tests.

For instance:

- In some shifts, lines were not fully prepared at startup, generating immediate urgencies.
- In others, early scrap removal allowed smoother operation later in the shift.
- Accumulation of finished pallets in EMG occurred when warehouse PF was saturated, creating congestion and additional movements.

The lack of a standardized start-of-shift routine significantly influences daily logistics performance.

3.6 Identification of Critical Issues

The analysis of the current internal logistics configuration highlights a set of structural and operational criticalities that limit overall efficiency and flow stability. Although the system ensures functional continuity and generally avoids prolonged production interruptions, its performance is strongly influenced by variability, lack of standardization, and reactive decision-making.

The first major issue concerns the absence of a structured replenishment logic. Material supply is managed through verbal communication and immediate response to perceived urgencies, rather than through predefined routes or fixed service cycles. This configuration generates workload fluctuations, inconsistent service intervals, and difficulty in predicting logistics performance.

A second critical aspect relates to warehouse organization. Storage locations are not systematically aligned with consumption frequency or proximity to production departments. Moreover, the three-shift structure leads to variability in material allocation practices, as each runner may adopt different positioning criteria. Over time, this creates inconsistencies in storage logic and increases dependency on individual experience for material retrieval.

The third issue involves transport inefficiencies. The spaghetti chart analysis revealed fragmented movement patterns, repeated crossings of central areas, and frequent interruptions of tasks due to emergency requests. These dynamics increase travel distances and reduce the overall efficiency of internal transport activities. The absence of route consolidation also contributes to repeated visits to the same departments within short time intervals.

Scrap management represents an additional operational constraint. Since scrap removal is handled reactively rather than through scheduled intervals, its prioritization can disrupt planned material supply activities. Although scrap disposal is essential to avoid machine stoppages, the lack of structured integration within the transport cycle contributes to workload imbalance.

Another relevant element concerns the concentration of diverse logistics responsibilities on a single operator per shift. The runner is simultaneously responsible for raw material replenishment, WIP transfer, packaging supply, pallet consolidation, finished goods transport, and waste handling. This task aggregation increases cognitive load and makes performance highly sensitive to sudden production changes.

Finally, the current configuration lacks measurable performance indicators related to internal logistics. Without standardized routes, defined service frequencies, or structured planning mechanisms, it is difficult to objectively evaluate improvements or quantify efficiency gains.

In summary, the critical issues identified can be grouped into four main categories:

- absence of standardized replenishment cycles,
- non-optimized warehouse allocation logic,

- inefficient and fragmented transport routes,
- excessive reliance on operator-dependent decision-making.

These elements confirm the need for a structured intervention aimed at stabilizing material flows, reducing variability, and improving coordination between warehouse organization and runner activities. The following chapter addresses warehouse reorganization as the first step toward establishing a more efficient and flow-oriented internal logistics system.

4 Warehouse Reorganization and Flow Optimization

Following the analysis of the existing internal logistics configuration and the identification of critical issues related to material handling variability, this chapter focuses on the practical reorganization of warehouse areas and storage logic. The intervention was not limited to improving order and cleanliness; rather, it aimed at structurally redesigning the allocation criteria of materials and packaging to support a more stable, predictable, and flow-oriented internal logistics system.

In the initial configuration, raw materials and packaging components were stored without a standardized allocation logic. Their positioning largely depended on individual runner experience and convenience during each shift. This approach generated inconsistencies across shifts, extended search times, and unnecessary internal movements, directly affecting line replenishment efficiency [7]. The absence of visual management tools and the lack of structured supermarket logic further amplified these inefficiencies.

Moreover, the introduction of new production lines—particularly those dedicated to bearing manufacturing—required the management of additional materials and packaging types, increasing system complexity. Without a clear zoning strategy and frequency-based storage criteria, the warehouse risked becoming a constraint rather than a support to production flow.

The reorganization project therefore pursued three main objectives:

1. To define clear storage zones aligned with production departments and material typologies.
2. To introduce frequency-based allocation criteria (high, medium, and low runner logic) to reduce unnecessary handling.
3. To implement visual management tools capable of standardizing storage logic and reducing dependency on individual knowledge.

This chapter describes the principles adopted for the reorganization, the new layout and zoning strategy, and the expected operational benefits in terms of flow stability, search time reduction, and overall logistics performance.

4.1 Reorganization principles adopted

The warehouse reorganization was structured as a progressive transition from a flexible but unregulated storage approach to a standardized and rule-based system. The objective was not simply to improve order, but to introduce allocation criteria capable of supporting internal logistics stability over time.

Rather than redesigning the layout arbitrarily, the intervention followed a sequence of logical steps. Firstly, the priority was to stabilize the existing configuration, eliminating non-value-adding elements and restoring basic operational clarity. Only after this phase, it was possible to define consistent storage rules aligned with production needs.

Additionally, two internal racks were installed directly inside the production area to create controlled buffers for high-rotation materials. This solution allowed runners to anticipate daily requirements based on production scheduling, reducing repetitive movements to the central warehouse without increasing overall inventory levels.

4.1.1 Preliminary Stabilization and Cleaning

The intervention began with a practical reset of the warehouse, addressing the existing conditions before defining new allocation rules. Rather than immediately introducing zoning criteria, it was necessary to first understand how space was being used and to remove the elements generating disorder.

All storage areas were reviewed in detail to identify unnecessary materials, unused space, and improper allocations. Obsolete items, damaged packaging, excess scrap, and materials no longer required for current production were removed. Where possible, outdated stock was returned or properly relocated based on actual operational needs.

This activity released occupied space and removed materials that were no longer required but still taking up storage capacity. It also clarified the real availability of racks and floor areas, allowing a more accurate assessment of storage potential.

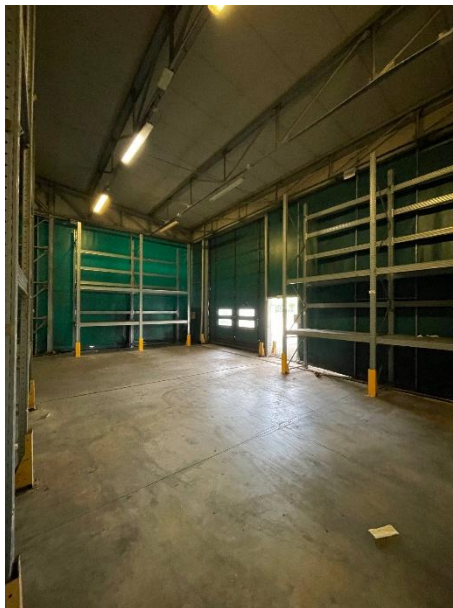


Figure 4.1 – Storage reorganization and cleaning

In parallel, racks and ground zones were cleaned and reorganized. Temporary placements that had gradually become permanent were eliminated, restoring a clearer separation between functional areas.

Without first restoring order and removing unnecessary materials, the introduction of structured zoning and frequency-based allocation would not have been effective. Only after this reset phase was it possible to proceed with a consistent reallocation of materials aligned with production departments and handling frequency.

4.1.2 Reorganization by Department and Functional Area

Once the warehouse was cleared and stabilized, the next step consisted of redefining the storage layout according to a clear zoning logic. The objective was to align the warehouse structure with the production structure, reducing overlaps between departments and limiting unnecessary internal movements.

Materials were reorganized based on two main criteria: production department and functional role [16].

From a departmental perspective, dedicated zones were defined for EMG, Unipiston, Heat Shield, and the newly installed Bearing production line. Previously, materials belonging to different departments were often mixed within the same rack areas. This generated cross-movements during replenishment activities, as runners frequently had to move between distant points to retrieve items for the same production area. By assigning each department to a clearly identifiable zone, internal logistics became more coherent and easier to manage.

From a functional perspective, specific areas were defined for:

- Inbound, where materials are temporarily positioned, after truck unloading, before being allocated to their final storage location. This separation allows faster unloading operations without interfering with operational stock.
- Passthrough, dedicated exclusively to temporary staging of outgoing products. Items stored in this area are not considered operational stock but are awaiting shipment.
- Shipping, where finished pallets prepared for same-day or next-day dispatch are positioned by logistics operators.
- Shared packaging area, containing materials used across multiple departments.
- Waste area, reorganized to include non-toxic waste such as gloves, plastic, and sealed oil containers, with proper separation from operational storage.

Additionally, heavy coils were assigned to a dedicated ground-level area to ensure safer handling and avoid congestion in rack zones.

This structured zoning eliminated ambiguity in material positioning. Each item now has a defined storage area based on its operational function and department. As a result, the warehouse layout reflects the logic of production flow.

4.1.3 Frequency-Based Storage Allocation

After defining the departmental and functional zoning, the next step consisted of reorganizing the internal structure of the racks according to material handling frequency. The objective was to align physical accessibility with real operational usage, reducing unnecessary movements and improving picking efficiency.

All racks are structured on three vertical levels. Instead of using this vertical space without distinction, each level was reassigned based on rotation frequency:

- High runner – materials handled on a weekly basis or more frequently.
- Medium runner – materials handled a few times per month.
- Low runner – materials handled only occasionally, typically a few times per year.

High-rotation items were positioned on the most accessible levels, generally at waist height, where picking and allocation require minimal effort and no additional equipment. Medium-rotation items were positioned on intermediate levels, while low-rotation materials were stored on upper levels, where access is less immediate.

This reallocation was based on actual consumption data, considering production schedules and the frequency with which each material is required during operations. The classification considered both replenishment frequency and the number of movements generated during runner cycles.

By positioning frequently used materials in easily accessible locations, picking time was reduced and repetitive bending or lifting movements were minimized [7]. At the same time, less frequently used items were moved away from prime positions, freeing space for high-rotation stock.

This logic also supports a pull-oriented approach. Packaging materials and several consumables are replenished based on real usage rather than fixed scheduling. When stock reaches a defined threshold, replenishment is triggered, following a simplified Kanban-like logic. Aligning storage accessibility with real consumption frequency improves responsiveness and reduces motion waste, while keeping overall inventory levels unchanged.

From the runner's perspective, this reallocation stabilizes workload. During replenishment cycles, high-rotation materials are retrieved quickly and predictably.

4.1.4 Introduction of Internal Racks in Production

During the reorganization process, two additional racks were installed directly inside the production area, each with a distinct operational function.

The first rack was dedicated to the phosphating department, which is physically located directly in front of the installed structure. The purpose of this solution was to optimize the overall distribution of tasks between production operators and the runner.

The phosphating area is continuously staffed by two operators. Due to the nature of the operations performed in this department, there are phases during which both operators are not simultaneously required on the machine. This operational characteristic allows them to manage short-distance replenishment activities without affecting production continuity.

By positioning the required materials directly in front of the department, operators can autonomously retrieve what is needed when necessary. This configuration avoids unnecessary runner intervention for activities that can be efficiently managed within the department itself.



Figure 4.2 – Rack B used by Phosphating department

The second rack serves a different purpose. It functions as a controlled buffer for high-rotation materials that are frequently required during the shift. Based on production scheduling visibility, runners allocate the necessary quantities at the beginning of the day or during planned cycles, anticipating consumption and reducing reactive calls from the line.

In addition to this buffer function, the rack is also used to temporarily store “incomplete pallets.” These are pallets that have not been fully filled with finished products because production of that specific item has been completed and no further quantity is currently required. Instead of moving these partially filled pallets to the finished goods warehouse, they

are positioned in this internal area and held until the next production cycle of the same product. Once production resumes, the pallets can be completed and then transferred for shipment.

This solution prevents unnecessary double handling and avoids occupying finished goods warehouse capacity with non-shippable stock. It also maintains visibility of pending quantities directly within the production area.

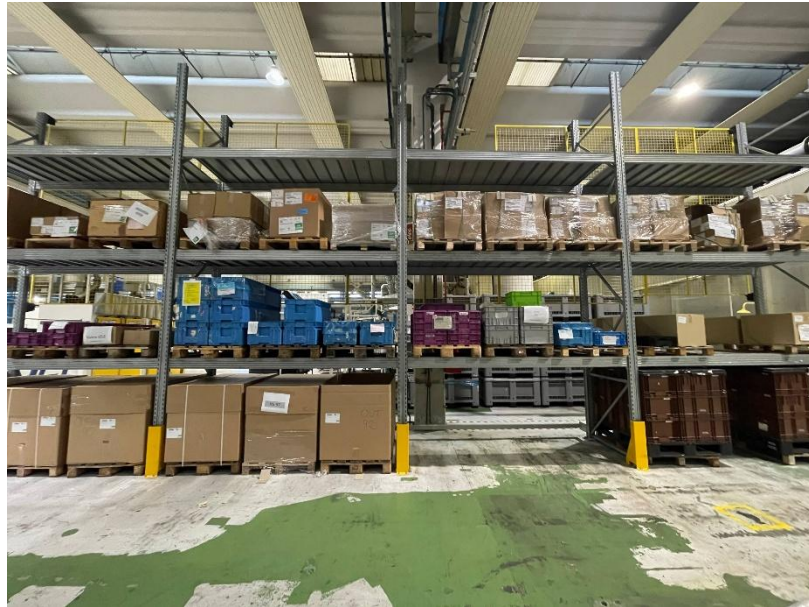


Figure 4.3 – Rack A

Overall, the introduction of these internal racks improves operational balance. One rack increases departmental autonomy and reduces runner workload in the phosphating area, while the other supports flow continuity by positioning frequently used materials closer to consumption and managing incomplete pallets in a structured way.

4.1.5 Visual Management and Material Identification

To ensure long-term stability of the new warehouse configuration, visual management tools were introduced as a structural component of the reorganization [17]. The objective was to reduce variability between shifts and eliminate dependency on individual knowledge for material identification and allocation.

Each rack was clearly labeled, and printed sheets indicating the allocated materials were positioned on the shelves [17]. This allows runners and operators to immediately identify the correct storage location without relying on verbal communication or prior experience. The visual indication of assigned materials reduces allocation errors and prevents progressive displacement of items over time.



Figure 4.4 – Label used to identify the material position on the shelves.

Within departmental zones, materials were grouped according to production cycle and, where applicable, customer. For example, in the EMG department, packaging dedicated exclusively to Volkswagen products was consolidated into a single identifiable area. This grouping simplifies replenishment during runner cycles and avoids mixing packaging belonging to different customers.

Attention was dedicated to the external area used for plastic KLT containers. Initially, these containers were stored without clear organization, increasing search time and creating disorder. A corridor-based identification system was introduced, using overhead signage combined with color coding and written labels. This visual system allows immediate recognition of container types and significantly reduces the time required to locate the correct KLT.

Overall, the introduction of visual management transformed the warehouse from a space dependent on individual familiarity into a structured and self-explanatory environment. This visual standardization supports the flow optimization described in the following sections by ensuring consistency, reducing search time, and stabilizing runner operations across shifts.

4.2 New layout for positioning the materials

Following the definition of the reorganization principles described in the previous section, the warehouse layout was redesigned to introduce a clear and structured allocation of materials across the available racks. Each rack was assigned a specific function based on three main criteria: proximity to the production department, type of material stored, and operational role within the internal logistics flow.

The layout includes racks identified with letters from A to T, distributed across the production area and the warehouse perimeter. This identification system allows immediate recognition of storage areas and simplifies communication between operators and runners.

The first two racks, A and B, are positioned directly inside the production area, in front of the phosphating department. Rack A is used to store incomplete pallets and to temporarily hold KLT containers used during the runner's shift. These incomplete pallets correspond to finished

product batches that could not be completed because production of that specific item has ended. Instead of transferring partially filled pallets to the finished goods warehouse, they are temporarily stored in this area until the next production batch allows completion and shipment.

Rack B serves as a small storage area dedicated to the phosphating department. Since this rack is located directly in front of the department, operators can autonomously retrieve the required materials when needed. This configuration improves the distribution of activities within the plant, allowing the runner to focus on departments where centralized replenishment remains necessary while operators manage short-distance material retrieval within their own working area.

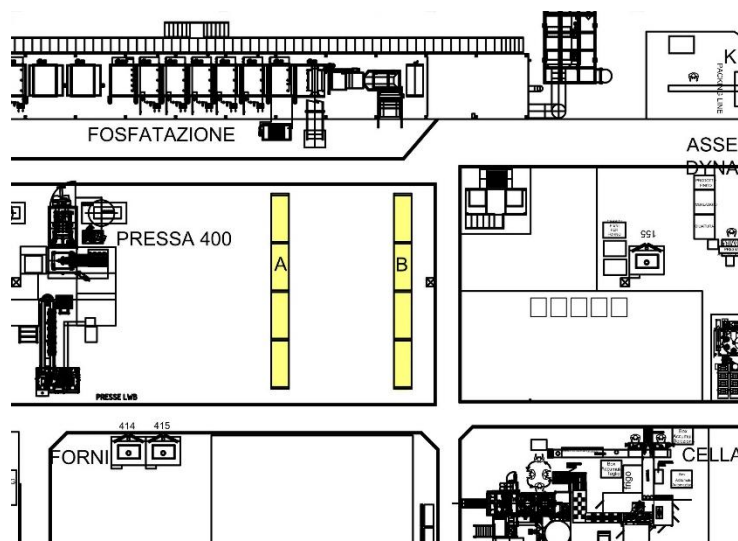


Figure 4.5 – New shelves

Racks C, D and E are located near the production area known internally as “Line 2”, where the bearing production lines are installed. These racks store the materials required for this specific production area. Their position was chosen to reduce the distance between storage and consumption points, allowing faster replenishment and providing operators with greater autonomy in accessing the materials required during production.

Rack F has a mixed function. Two of its bays, those located closest to the containment trays represented in the layout, are dedicated to waste management. These areas are used for storing non-toxic waste such as gloves, plastic materials and sealed containers for used oils. The remaining bays of the rack are assigned to materials used by the Unipiston and Heat Shield departments.

Rack G is entirely dedicated to the Unipiston and Heat Shield departments. These departments require relatively limited packaging storage inside the warehouse because finished products are mainly shipped using plastic KLT containers, which are stored in the external area of the plant. As a result, the materials stored in this rack are mainly trays and intermediate handling components used during the production process.

Rack H contains materials shared by multiple departments across the plant. These typically include general packaging materials such as bubble wrap, protective elements, and large cardboard boxes used when specific packaging solutions are required. Positioning these items in a central rack ensures accessibility from multiple production areas and simplifies the management of shared consumables.

Racks I, L, M, N, O and P are entirely dedicated to the EMG department, which requires the largest variety of packaging materials. Unlike other departments, EMG products are predominantly shipped using cardboard packaging rather than plastic containers. Consequently, a large portion of the stored materials consist of flat cardboard boxes, box lids, separators, protective sheets and other packaging components that must be assembled during packing operations.

Within these racks, packaging materials were grouped primarily by final customer when possible. For example, materials dedicated to specific automotive customers were consolidated in identifiable sections, while other elements were organized according to their function, such as box components, lids, separators or protective sheets. This classification reduces search time during packaging operations and simplifies material identification during runner cycles.

In addition, racks O and P also accommodate heavy wooden crates containing graphite. Due to their significant weight and size, these crates are stored at ground level to ensure safe handling and avoid unnecessary lifting operations.

Rack Q also supports the activities of the kitting department. This department produces aftermarket kits that are sealed in their dedicated packaging. The finished kits are placed on pallets and temporarily stored on the racks before shipment. The rack also contains components used during the packaging process, such as branded cardboard inserts and sealed bags.

Rack R is partially dedicated to the passthrough area. Three bays are used for temporarily storing finished products that are ready for shipment but have not yet been loaded onto trucks. Some of these products are placed inside large metal containers that require significant storage space. The remaining bays of rack R are used for shipping preparation. Since finished pallets are typically completed and closed either on the same day or the day before shipment, only a limited number of bays is required. This approach supports the company's just-in-time production strategy by avoiding the creation of unnecessary finished goods stock.

Finally, racks S and T are dedicated to the inbound area. This zone is used for temporarily positioning incoming materials and coils immediately after truck unloading. By allocating dedicated inbound space, trucks can be unloaded quickly without interfering with operational storage areas. Once unloading operations are completed, materials are progressively allocated to their final storage locations.

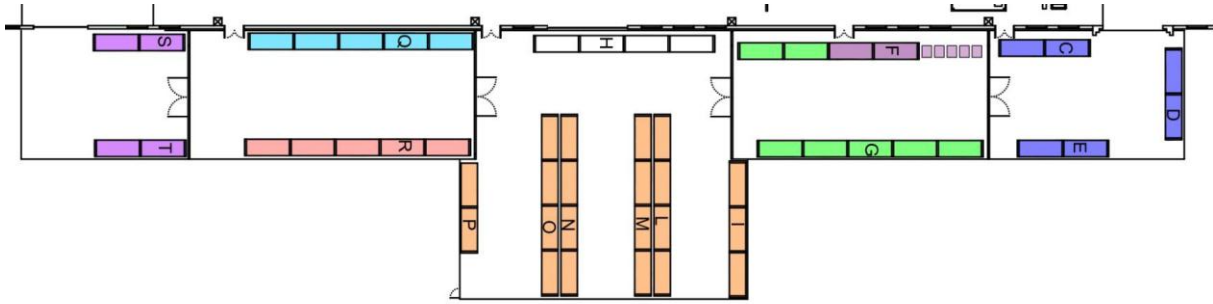


Figure 4.6 – Warehouse reorganization

The external area of the warehouse, which already existed before the reorganization, was also reorganized to improve storage clarity. Plastic KLT containers are stored in this zone, and visual management tools were introduced to organize them into clearly identifiable corridors.



Figure 4.7 – KLT containers storage

Overall, the new layout transforms the warehouse into a structured environment where each rack performs a clearly defined role. Storage locations are now aligned with production departments and logistics functions, reducing internal movements, simplifying material identification, and supporting a more stable internal logistics flow.

4.3 Expected outcomes

The analysis of internal material handling activities highlighted several inefficiencies in the original warehouse configuration. The study of operator movements, supported using spaghetti

charts, made it possible to visualize the paths followed by runners and forklift operators when retrieving packaging materials or transporting pallets within the warehouse areas. The analysis revealed that many routes were unnecessarily long and often circuitous. In the previous configuration, storage positions were not organized according to a clear allocation logic, and materials belonging to different departments were frequently mixed within the same rack areas. Consequently, operators were often required to move across multiple zones of the warehouse to retrieve materials needed within the same production cycle.

These inefficiencies were further amplified by the lack of standardized storage locations and by the absence of a clear visual identification system. In fact, in several cases, the actual position of pallets did not correspond to the information available to operators, forcing them to perform manual checks before locating the correct materials. This situation generated additional search time, increased the number of internal movements, and introduced variability between shifts depending on the experience of individual runners.

From an operational perspective, these conditions had a direct impact on warehouse productivity and on the stability of internal logistics flows. Longer search times and inefficient routes increased handling times and reduced the responsiveness of the logistics system to production requests.

The reorganization described in the previous sections addressed these issues through a combination of zoning, frequency-based storage allocation, and the introduction of visual management tools. In addition to improving the logical structure of the warehouse, the intervention also increased the available storage capacity.

The transition from the previous configuration of 16 racks to the current layout of 18 racks, including the two additional racks installed in the production area, allowed an expansion of the available storage space. Considering the four-level rack configuration and the possibility of storing up to three pallet positions per rack bay (with a standard pallet size of approximately 900×1000 mm), the intervention generated an increase of 96 additional storage cells.

This corresponds to a 16.44% increase in storage capacity, moving from 584 to 680 storage positions. The additional racks were installed in an area that had previously been unused, as it was previously occupied by a machine that was later removed. The newly available space made it possible to better accommodate pallets containing packaging materials, finished goods, and partially completed pallets, reducing the need for temporary placements and improving the overall organization of the warehouse.

Beyond the increase in storage capacity, one of the most relevant improvements concerned the reduction of material search times. In the previous configuration, the lack of structured storage rules made the identification of pallets particularly time-consuming. On average, logistics operators required approximately five minutes to locate a single pallet.

Considering that around 20 pallets are handled during a typical shift, and that the plant operates three shifts per day from Monday to Friday, this results in approximately:

- 780 shifts per year
- About 15,000 pallet movements annually

Under the previous configuration, the time spent searching for pallets amounted to approximately:

$$15,000 \text{ pallets} \times 5 \text{ minutes} \approx 1,250 \text{ hours per year}$$

Assuming an average labor cost of 24 €/hour, the annual cost associated with material search activities alone was approximately:

$$1,250 \text{ hours} \times 24 \text{ €/hour} \approx 30,000 \text{ € per year}$$

Following the warehouse reorganization and the introduction of structured rack allocation and visual identification, observations conducted over a one-month period after the implementation of the new system showed that the time required to locate a pallet was reduced to approximately one minute. The clearer layout and the grouping of materials by department and function significantly simplified the identification of storage locations.

Based on the same calculation used previously, the annual time dedicated to searching for materials was therefore reduced to approximately 250 hours per year.

This corresponds to an annual cost of:

$$250 \text{ hours} \times 24 \text{ €/hour} \approx 6,000 \text{ €}$$

As a result, the intervention generated an estimated saving of approximately 24,000 € per year, corresponding to a reduction of roughly 80% of the previous cost associated with material search activities.

In addition to these measurable economic benefits, the reorganization also produced several operational improvements. The clearer storage logic and the alignment between warehouse zones and production departments reduced unnecessary movements and made picking activities more predictable. Operators are now able to identify storage locations more quickly, and the risk of misplaced pallets has been significantly reduced.

The project required an initial investment of approximately 12,000 €, mainly related to the installation of the two additional racks. Considering the annual savings generated by the reduction in search time alone, the investment was recovered in approximately six months, after which the improvements began to generate a net economic benefit.

Overall, the warehouse reorganization not only improved storage capacity and reduced operational costs but also created the structural conditions necessary to support more stable and efficient internal logistics flows within the plant.

5 Standardization of Runner Activities

After the reorganization of the warehouse layout and the introduction of a structured storage logic described in the previous chapter, the focus of the project shifted toward the optimization of internal material handling activities. While the new warehouse configuration significantly improved storage organization and material accessibility, the overall efficiency of the logistics system still depended on how materials were physically transported between the warehouse and the production departments.

In the Chivasso plant, this task is mainly performed by a dedicated operator commonly referred to as the runner. The runner is responsible for a wide range of internal logistics operations that are essential to the continuity of production. These activities include supplying raw materials and packaging to the production lines, transporting finished product pallets to the shipping area, handling empty containers, and supporting several operational activities within the plant. In addition, the runner is also involved in the removal of waste generated by production processes and in the management of auxiliary materials required during daily operations.

Because of this wide range of responsibilities, the runner plays a key role in ensuring that production processes can operate without interruptions. Any delay in the supply of materials or in the removal of finished products can directly affect the continuity of production lines. For this reason, the efficiency of runner activities has a direct impact on the overall performance of the plant.

During the initial phase of the internship, several observation sessions were carried out to understand how these activities were performed in practice. The analysis included direct observation of daily operations, discussions with production operators and team leaders, and the collection of operational data related to internal material flows. Attention was dedicated to identifying the routes followed by the runner, the types of materials transported, and the frequency of the different logistics activities performed during each shift.

This analysis revealed that, prior to the implementation of the project, runner activities were largely reactive rather than structured. Material supply operations were mainly triggered by requests from production operators when materials were about to run out at the machines. In many cases, these requests were communicated verbally or through direct calls to the runner, creating a system heavily dependent on real-time communication rather than on a predefined logistics plan.

Consequently, the runner did not follow a consistent sequence when moving through the plant. Routes varied continuously depending on the urgency of requests received during the shift. This lack of structure often resulted in inefficient movement patterns, with operators travelling across different production areas multiple times to complete unrelated tasks.

In some cases, several machines require supplies at the same time, forcing the runner to prioritize requests and increasing the risk of temporary material shortages at certain workstations.

Another issue identified during the analysis concerned the limited visibility of material needs across the production departments. Since supply requests were generated only when materials were nearly exhausted, the system frequently operated under time pressure. This situation increased the likelihood of delays and reduced the possibility of planning internal logistics activities in an efficient manner.

The absence of standardized logistics cycles also made it difficult to balance the workload of the runner during the shift. Certain periods were characterized by intense activity due to multiple simultaneous requests, while other moments involved idle time caused by the absence of scheduled tasks. This irregular distribution of work reduced the overall efficiency of the internal logistics system and increased the variability of response times.

These findings highlighted the need to introduce a more structured approach to internal material handling, consistent with lean logistics principles aimed at reducing transport inefficiencies and stabilizing material flows [7]. In particular, the project aimed to transform the existing reactive system into a standardized and cyclic logistics process, capable of ensuring a regular and predictable supply of materials to production lines. To achieve this objective, the concept of milk-run logistics was adopted as the reference model for redesigning the runner workflow [18].

The milk-run approach is based on the principle of cyclic material distribution, where an operator follows a predefined route through the production areas, supplying materials and collecting empty containers at regular intervals. Instead of responding to individual requests, materials are delivered according to a fixed schedule and a structured sequence of activities. This approach improves the stability of internal flows, reduces unnecessary movements and ensures that production lines receive the required materials in a timely and consistent manner.

The introduction of this system required a detailed understanding of the existing logistics flows, including the identification of the main material movements, the machines involved, and the time required for each operation. The following sections of this chapter will therefore present the analysis of the previous runner workflow, followed by the design of a standardized milk-run system and the definition of the optimized routes and activities.

Finally, a time and economic analysis will be presented to evaluate the impact of the proposed solution on internal logistics efficiency and overall operational performance.

5.1 Analysis of previous runner workflow

Before introducing a standardized internal logistics system, it was necessary to analyze in detail how runner activities were performed in the initial configuration of the plant. This phase focused on understanding the actual workload of the runner during a typical shift, the types of operations carried out, and the way these activities were organized across the production and warehouse areas.

The analysis was based on direct observation of runner activities over a two-week period, supported by the systematic collection of operational data during multiple shifts. Throughout this period, all logistics operations performed by the runner were monitored to capture both the variability and the recurrence of the different tasks. The collected data showed a consistent pattern of activities across shifts, confirming the repetitive nature of internal logistics operations.

For the purpose of clarity and readability within this work, one representative activity log was selected and structured into a detailed table, reporting the sequence of operations performed during a full shift together with their execution times. The table, shown in Table 5.1, provides a synthetic but representative overview of the runner's workload over an 8-hour shift.

	ACTIVITY	WHERE	QUANTITY	Time (min)
1	Alignment with Team Leader			15
2	Full cart transfer from Cella 2 to oven	CELLA 2	1	15
3	Empty cart handling in Cella 2	CELLA 2	1	
4	Empty metal container handling	400	1	10
5	Full metal container handling	400	1	
6	Pallet handling with KLT for selection	SELECTION	1	5
7	Scrap removal	400	2	10
8	Waste and scrap disposal	P51	2	15
9	Pallet handling with KLT (Nissan)		1	10
10	Logistics support activities			45
11	Coil transport	AIDA AND OMER A	2	15
12	Break			10
13	Logistics support activities			40
14	Waste collection	AIDA AND OMER A	2	15
15	Finished product handling	SELECTION	1	25

16	Lids handling	SELECTION	3	
17	Empty pallet handling (Daimler)	SELECTION	1	
18	Pallet handling with KLT (Daimler)	SELECTION	1	
19	Finished product handling	MA4	1	20
20	Return of pallet with KLT and empty pallet	MA4	2	
21	Finished product handling	MA7	1	15
22	Return of pallet with cardboard boxes	MA7	2	
23	Pallet handling with cardboard boxes (Mercedes)	MA8	1	10
24	Break			30
25	Waste collection	EMG/GASKET	3	25
26	Iron pallet and KLT handling (BMW)	LINE HS1	4	15
27	Forklift charging			5
28	Full cart transfer from Cella 2 to oven	CELLA 2	1	30
29	Full cart transfer from Line 400 to oven	400	1	
30	Pallet handling (BMW)	LINEA HS1	1	
31	Break			10
32	Empty pallet handling and check for incomplete pallets (BMW)	LINE HS1	2	10
33	Waste inspection			20
34	Replacement of metal container	400	2	15
35	Preparation of KLT and coils for next shift			25
36	Shift handover			20
	TOTAL TIME (hours)			8

Table 5.1 – Runner's workload over an 8-hour shift

From these observations, it emerged that the runner is responsible for a wide range of logistics tasks that can be grouped into a few main categories. The first category includes material supply to production lines, such as the delivery of raw materials (e.g. coils), packaging materials (KLT containers, cardboard boxes), and pallets required for ongoing production. These activities are essential to ensure that machines can operate without interruptions.

A second category concerns the handling of finished products, including the removal of completed pallets from production areas and their transfer to intermediate storage or shipping zones. In several cases, this also involves the management of partially completed pallets, which are temporarily stored and later reintegrated into the production flow.

Another important set of activities is related to the management of empty containers and internal transport units, such as empty KLT, pallets, and metal containers. These items must be continuously collected, repositioned, and redistributed across the plant to support ongoing operations.

Finally, the runner is also responsible for waste and scrap handling, which includes the removal of production scrap, emptying of waste containers, and transport of materials to dedicated external areas. Although these activities do not directly contribute to product transformation, they are necessary to maintain a safe and organized working environment.

The analysis of the activity tables highlights that these operations are distributed throughout the entire shift and are interleaved in a non-structured manner. A typical shift includes several repetitions of similar tasks, such as supplying materials, removing finished products, and managing waste, but without a consistent execution sequence. The time required for individual activities varies significantly, ranging from short operations of a few minutes to longer tasks involving multiple movements across the plant.

In addition to the activity logs, the observation of runner movements within the plant was supported by the use of a spaghetti chart Figure 5.1, which visually represents the paths followed during a shift.

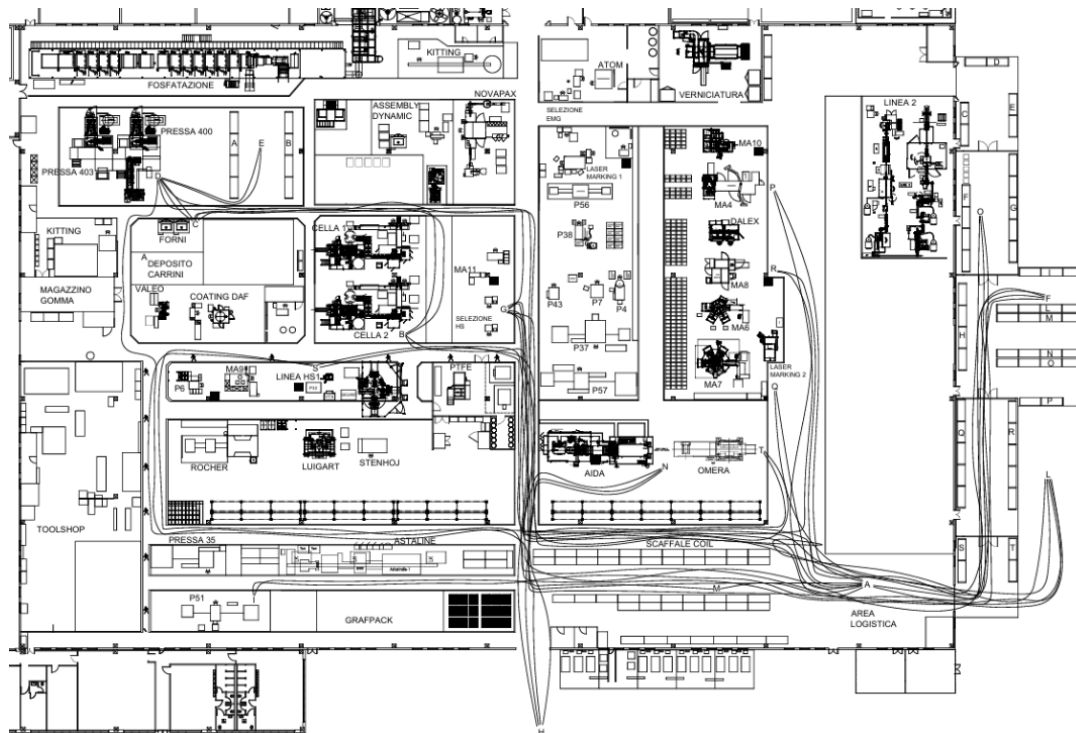


Figure 5.1 – Visualization of runner movements by the use of a spaghetti chart

The spaghetti diagram highlights a key aspect of the previous workflow: the runner does not follow a structured route but rather moves across the plant in a fragmented and irregular way. The paths are characterized by frequent back-and-forth movements between different areas, often covering the same zones multiple times within a short time interval. This pattern results in an increase in total travel distance and contributes to higher execution times for logistics operations.

One of the main causes of this behavior is the absence of a predefined supply sequence. In the initial configuration, the runner did not operate according to a fixed route or schedule. Instead, activities were mainly triggered by real-time requests from production operators or team leaders. These requests were typically communicated through direct phone calls, verbal communication, or by intercepting the runner while moving within the plant.

This request-based system introduced a high level of variability in the workflow. The order in which tasks were performed changed continuously depending on the urgency of requests received during the shift. As a result, the runner often had to interrupt ongoing activities to respond to new demands, leading to fragmented movements and inefficient use of time.

A critical consequence of this approach is the lack of route optimization. Since tasks are executed individually and not grouped logically, the runner frequently travels empty between different locations or performs partial loads. In many cases, the forklift or stacker is not fully utilized, as materials are transported one at a time instead of being consolidated into a single movement. This results in a significant number of non-value-added movements, increasing both time and operational costs, as typically observed in non-structured internal logistics systems [7].

Another important inefficiency identified during the analysis concerns the time spent searching for materials within the warehouse. Before the reorganization described in Chapter 4, the storage of packaging materials, pallets, and containers was not based on a structured allocation logic. Materials were often placed according to available space or operator convenience, without a clear identification system.

As a result, the runner frequently had to spend additional time locating the required items, such as specific KLT containers, pallets, or packaging materials. This issue is reflected in the activity logs, where several operations implicitly include search time within the total execution time. The lack of visual management and standardized storage positions increased variability between shifts and made the process strongly dependent on the experience of individual operators.

This aspect is directly connected to the warehouse conditions described in the previous chapter. The absence of defined storage logic and the lack of clear identification tools contributed to increasing the time required for each supply operation, further reducing the overall efficiency of the internal logistics system.

The combined effect of these factors results in a workflow characterized by high variability and limited predictability. The runner's activities are not evenly distributed over time, with periods of intense workload alternating with moments of inactivity. This imbalance is mainly due to the reactive nature of the system, where multiple requests can occur simultaneously, forcing the runner to prioritize certain operations while delaying others.

In a production environment characterized by just-in-time principles, this lack of structure represents a significant limitation. The absence of a planned supply system increases the risk

of material shortages at the machines, potentially leading to production interruptions. At the same time, it can also generate local overstock situations, where materials are delivered earlier than necessary due to inefficient coordination.

The analysis of the previous runner workflow therefore highlights three main critical aspects:

- the absence of a standardized route, resulting in fragmented movements and increased travel distances
- the lack of load optimization, with frequent empty or partially loaded movements
- the inefficiencies related to material search within the warehouse, caused by the lack of structured storage logic

In addition to these factors, the strong dependence on real-time communication between production and logistics further contributes to inefficiencies, making the system difficult to control and optimize.

These findings clearly indicate the need for a more structured approach to internal logistics. The repetitive nature of the activities performed by the runner suggests that it is possible to reorganize these operations into a predefined and cyclic workflow. This approach would allow grouping multiple tasks within a single route, reducing unnecessary movements and improving the overall efficiency of the system.

The following section will therefore focus on the design of a standardized milk-run system, aimed at transforming the current reactive workflow into a structured and repeatable logistics process capable of supporting production in a more stable and efficient way.

5.2 Design of a standardized milk-run

The analysis of the previous runner workflow highlighted a system characterized by high variability, lack of structure, and strong dependence on real-time requests from production departments. Although the activities performed by the runner were repetitive in nature, they were managed in a reactive way, leading to inefficient movements, unbalanced workload distribution, and limited control over internal logistics flows.

In order to address these issues, the project focused on the design of a standardized milk-run system, with the objective of transforming the existing request-based workflow into a structured and repeatable logistics process.

From a theoretical perspective, the adoption of a milk-run system is consistent with the principles described in Section 1.3.5, particularly in relation to flow optimization, reduction of non-value-added activities, and implementation of pull-based material supply [7]. However, the choice to introduce this system was not only driven by theoretical considerations, but also by specific operational needs observed within the plant.

One of the main objectives was to increase the overall efficiency of the runner's activities, reducing time losses associated with disorganized movements and enabling a more effective use of available resources. In particular, the introduction of a structured logistics cycle makes it possible to reduce the time required for material handling operations, allowing the runner to dedicate more time to supporting activities in the shipping area, such as pallet closing and preparation of finished products.

At the same time, the milk-run system enables the definition of a standard and predictable workflow, reducing the variability observed in the previous configuration. By following a predefined route, the runner is no longer required to react continuously to incoming requests, but can operate according to a structured sequence of activities. This improves the stability of internal flows and reduces the dependence on individual experience.

Another key objective of the design was to maintain a certain degree of operational flexibility. Although the milk-run introduces a fixed cycle, it does not eliminate the possibility of handling urgent requests. On the contrary, by reducing the overall time spent on standard activities, the system creates additional capacity that can be used to manage unexpected situations, such as last-minute production changes or urgent material needs.

5.2.1 Machine Selection Criteria

A fundamental step in the design of the milk-run system was the selection of the machines and workstations to be included in the standardized route.

The initial analysis considered all the machines present in the production area. However, not all of them were included in the final configuration. The selection was based primarily on the frequency of use and the intensity of logistics interactions associated with each machine.

Machines characterized by very low utilization, operating only a few times per year or sporadically during the month, were excluded from the milk-run. For these cases, a direct intervention based on occasional requests does not generate significant inefficiencies and therefore does not justify their inclusion in a cyclic logistics system.

In addition, some activities related to specific machines were already managed autonomously by operators through the use of localized supermarket areas, as described in Chapter 4. In these cases, raw materials and work-in-progress components are stored directly near the machines, allowing operators to handle internal movements without involving the runner. As a consequence, only specific logistics activities, such as the handling of finished products or the replenishment of empty containers, were considered for inclusion in the milk-run.

Examples of this approach can be observed in several areas of the plant, where internal movements of materials are performed using small carts directly by production operators. This configuration reduces the need for centralized logistics intervention and contributes to a more efficient distribution of tasks.

The final selection therefore focused on machines and areas characterized by:

- frequent material supply requirements
- regular generation of finished product pallets
- continuous need for handling containers and packaging materials

At the same time, the route was designed to be independent from the actual operating condition of each machine. This means that the milk-run can be executed even if some machines are not active during a specific shift. In such cases, the runner simply skips the corresponding stop, maintaining the overall structure of the route without introducing variability.

	MILK RUN
GRAFPACK	NO
P51	NO
ASTALINE	NO
PRESSA 35	NO
STENHOJ	SI
LUIGART	SI
ROCHER	SI
P6	SI
MA9	SI
LINEA PSA/HS1	SI
VALEO	SI
COATING DAF	SI
CELLA 1 E 2	SI
SELEZIONE HS	SI
MA11	SI
PRESSA 400 E 403	SI
ASSEMBLY DINAMIC	SI
NOVAPAX	SI
ATOM	NO
SELEZIONE EMG	SI
LASER MARKING 1	SI
P56	SI
P43	NO
P37	SI
P57	SI
P38	NO
AIDA	SI
OMERA	SI
MA10	SI
MA4	SI
DALEX	SI
MA8	SI
MA6	NO
MA7	SI
LASER MARKING 2	SI
LINEA 2	SI
KITTING	NO
FOSFATAZIONE	NO

Figure 5.2 – List of machines considered in the milk run.

5.2.2 Reduction of Empty Movements

One of the central aspects of the milk-run design concerns the reduction of non-value-added movements, in particular empty trips performed without carrying materials.

In the previous workflow, the runner frequently moved between different areas of the plant without transporting any load, or with partially loaded equipment. This was mainly due to the reactive nature of the system and the lack of coordination between different logistics activities.

The new system was therefore designed with the objective of maximizing load utilization during each movement. Whenever possible, the runner is required to move with the forklift or stacker fully loaded, combining multiple activities within the same trip.

This means that a single movement can include:

- delivery of materials to a machine
- collection of empty containers
- removal of finished products
- transport of waste or scrap

By integrating these operations, the number of trips required during the shift is reduced, and the efficiency of each movement is increased.

This approach is consistent with Lean principles, where internal transport is considered a non-value-added activity that must be minimized and optimized. Ensuring that each movement generates value, by carrying materials instead of empty loads, contributes to reducing overall handling time and improving productivity.

5.2.3 Integration with Warehouse Reorganization

The effectiveness of the milk-run system is closely related to the warehouse reorganization described in Chapter 4. The introduction of a structured storage logic, based on defined locations and visual management, significantly reduced the time required to locate materials.

In the previous configuration, the lack of organization within the warehouse forced the runner to spend additional time searching for pallets, KLT containers, and packaging materials. This issue limited the effectiveness of any attempt to standardize logistics activities.

With the new warehouse layout, materials are stored according to clear allocation criteria, making them immediately identifiable. This condition represents a necessary prerequisite for the implementation of a cyclic logistics system, as it allows the runner to perform operations quickly and consistently without interruptions.

5.2.4 From Reactive to Structured Logistics

Overall, the design of the milk-run system represents a transition from a reactive and operator-dependent workflow to a structured, repeatable, and more efficient logistics process.

By organizing activities into a predefined cycle, it becomes possible to:

- stabilize internal material flows
- reduce unnecessary movements
- balance the runner's workload during the shift
- improve coordination between warehouse and production

At the same time, the system maintains the flexibility required to manage unexpected events, ensuring that production needs can still be addressed when necessary.

The next section will describe how this design has been translated into a concrete operational workflow, detailing the route followed by the runner and the specific activities performed at each stage of the cycle.

5.3 Route and activities definition

The design of the standardized milk-run led to the definition of a structured and repeatable route, developed on the basis of the layout reorganization and the analysis of internal material handling activities.

5.3.1 Route definition

The route has been designed as a closed and continuous loop that connects the main logistics and production areas of the plant, reflecting the cyclical service logic typical of milk-run systems [18]. Starting from the warehouse and logistics zones, the runner follows a predefined path that sequentially serves the different production departments, before returning to the starting point.

The definition of the route was driven by three main objectives:

- minimizing unnecessary movements across the plant
- avoiding repeated visits to the same areas
- ensuring a balanced coverage of all relevant machines

Compared to the previous configuration, where movements were strongly influenced by extemporaneous requests, the new route follows a fixed sequence that allows the runner to serve multiple workstations within a single pass. This eliminates the need for frequent back-and-forth movements between distant areas of the plant.

5.3.2 Activities organization along the route

A key improvement introduced by the milk-run is the integration of multiple activities within each stop. In the previous system, operations such as material delivery, empty container collection, and waste handling were often performed in separate moments, requiring multiple visits to the same machine or area.

In the proposed configuration, these activities are grouped and executed during a single stop. As shown in Figure 5.3, each phase of the route includes a combination of:

- delivery of materials required for production

- collection of empty pallets and KLT containers
- removal of waste and scrap when necessary

This integrated approach significantly reduces the total number of movements required to complete a full cycle and improves the overall efficiency of the system.

MOVEMENTS	FULL/EMPTY	FROM	TO	MATERIAL
1	F	Coil Storage	Omera + Aida	Coil
2	F	Waste area	Omera + Aida	Scrap
3	F	Warehouse	Stenhoj + Lulgart	Packaging
4	F	Waste area	Stenhoj + Lulgart	Scrap
5	F	Coil Storage	Rocher	Coil
6	F	Waste area	Rocher	Scrap
7	F	Warehouse	P6	Packaging
8	F	P6	Warehouse	Finished Product
9	F	Warehouse	MA9	Packaging
10	F	MA9	Warehouse	Finished Product
11	F	Warehouse	Coating DAF	Packaging
12	F	Coating DAF	Warehouse	Finished Product
13	F	Warehouse	Valeo	Packaging
14	F	Valeo	Warehouse	Finished Product
15	F	Warehouse	Pressa 400 + 403	Packaging
16	F	Pressa 400	Fosfatazione	Empty Kart of phosphated metals
17	F	Fosfatazione	Pressa 400	Kart with phosphated metal
18	F	Pressa 400	Fosfatazione	Empty Kart of phosphated metals
19	F	Fosfatazione	Pressa 403	Kart with phosphated metal
20	F	Pressa 400 + 403	Waste area	Scrap
21	E	Waste area	Warehouse	
22	F	Warehouse	Assembly Dynamic	Packaging
23	E	Assembly Dynamic	Oven	Finished Product in kart
24	E	Oven	Pressa 400 + 403	
25	F	Pressa 400 + 403	Oven	Finished Product in kart
26	E	Oven	Fosfatazione	
27	F	Fosfatazione	Novapax	Kart with phosphated metal
28	F	Novapax	Fosfatazione	Empty Kart of phosphated metals
29	F	Fosfatazione	Cella 1	Kart with phosphated metal
30	F	Cella 1	Fosfatazione	Empty Kart of phosphated metals
31	F	Fosfatazione	Cella 2	Kart with phosphated metal
32	F	Cella 2	Fosfatazione	Empty Kart of phosphated metals
33	E	Fosfatazione	Cella 1	
34	F	Cella 1	Oven	Finished Product in kart
35	E	Oven	Cella 2	
36	F	Cella 2	Oven	Finished Product in kart
37	E	Oven	Warehouse	
38	F	Warehouse	Linea HS1	Packaging
39	F	Linea HS1	Warehouse	Finished Product
40	F	Warehouse	Selezione HS	Packaging
41	E	Selezione HS	Aida	
42	F	Aida	Waste area	Scrap
43	E	Waste area	Coil Storage	
44	F	Coil Storage	P57	Coil
45	E	Selezione HS	Omera	
46	F	Omera	Waste area	Scrap
47	E	Waste area	Coil Storage	
48	F	Coil Storage	P37	Coil
49	E	Selezione HS	Rocher	
50	F	Rocher	Waste area	Scrap
51	E	Waste area	Coil Storage	
52	F	Coil Storage	P56	Coil
53	E	P56	Warehouse	
54	F	Warehouse	MA11 + Laser Marking 1	Packaging
55	E	MA11 + Laser Marking 1	Warehouse	
56	F	Warehouse	Linea 2	Packaging
57	F	Linea 2	Warehouse	Finished Product
58	F	Warehouse	MA10	Packaging
59	F	MA10	Warehouse	Finished Product
60	F	Warehouse	MA4	Packaging
61	F	MA4	Warehouse	Finished Product
62	F	Warehouse	DALEX	Packaging
63	F	DALEX	Warehouse	Finished Product
64	F	Warehouse	MA8	Packaging
65	F	MA8	Warehouse	Finished Product
66	F	Warehouse	Laser Marking 2	Packaging
67	F	Laser Marking 2	Warehouse	Finished Product
68	F	Warehouse	MA7	Packaging
69	F	MA7	Warehouse	Finished Product

Figure 5.3 – Milk-run activities

5.3.3 Reduction of empty travel

One of the main limitations identified in the initial analysis was the high number of empty movements performed by the runner. These movements were mainly caused by the lack of planning and by the need to respond to urgent requests.

The proposed milk-run addresses this issue by structuring the route in such a way that the handling equipment is utilized as efficiently as possible. The sequence of activities has been defined to ensure that, whenever possible, the runner alternates delivery and pickup operations, maintaining the forklift loaded for most of the route.

Although some empty movements cannot be completely eliminated due to operational constraints, their frequency is significantly reduced compared to the previous configuration. This results in a more efficient use of time and resources.

5.3.4 Elimination of back-and-forth movements

Another key improvement concerns the elimination of unnecessary back-and-forth movements between areas. In the previous system, the runner frequently moved multiple times between the same locations within a single shift, generating inefficiencies and increasing handling time.

The new route is designed to follow a logical progression across the plant, avoiding repeated crossings of the same zones. Each area is visited once per cycle, and all required activities are completed before moving to the next location. This results in a more linear and streamlined flow of movements.

5.3.5 Consistency with milk-run principles

The proposed solution fully reflects the principles introduced in the previous sections. In particular, the system ensures:

- a standardized and repeatable sequence of operations
- a reduction of variability between shifts
- a more predictable and stable material flow
- improved coordination between production and logistics

The introduction of a structured route also reduces the dependency on operator experience, as the sequence of activities is predefined and does not rely on individual decision-making.

5.3.6 Operational outcomes

Overall, the definition of the milk-run route leads to a more organized and efficient internal logistics system. The runner operates within a clear framework, following a predefined path that minimizes waste and improves time management.

The combination of layout reorganization and route standardization allows reducing unnecessary movements, improving the utilization of handling equipment, and ensuring a more reliable supply of materials to production.

5.4 Time and Economic analysis

The introduction of the standardized milk-run enables a structured evaluation of the improvements achieved in internal logistics. The analysis is based on a comparison between the previous operating conditions (AS-IS) and the proposed system (TO-BE), considering both time efficiency and operational impact.

5.4.1 Time analysis

The time analysis is based on the comparison between the runner workflow observed in Section 5.1 and the same set of activities reorganized according to the milk-run logic.

In the initial analysis, the runner performed activities without a predefined sequence, moving across the plant mainly in response to requests from operators and team leaders. This resulted in a high number of non-value-added movements, including empty travel, repeated visits to the same machines, and inefficient routing.

By applying the milk-run logic to the same set of activities, it is possible to estimate a significant reduction in execution time. The introduction of a predefined route, combined with the integration of multiple operations within a single stop, allows minimizing unnecessary movements and improving the overall organization of the workflow.

Based on this comparison, the time required to perform the same activities can be reasonably estimated to decrease by approximately 30% compared to the previous configuration.

This reduction is mainly associated with:

- elimination of back-and-forth movements
- reduction of empty travel
- improved sequencing of operations
- elimination of time losses related to call-based requests

In addition to this comparison, the full milk-run cycle, as defined in Section 5.3, has been analyzed. Considering the complete route covering all the selected machines and logistics activities, the duration of a full cycle is estimated at approximately 3 hours per complete cycle.

It is important to note that this complete cycle represents a reference scenario. In real operating conditions, the runner will not execute the full route in every cycle, but only the sequence of machines that are active during the specific shift. As a result, the actual execution time will vary depending on production conditions, while maintaining the same structured logic.

5.4.2 Operational impact

The introduction of the milk-run has a direct impact on the organization of internal logistics activities.

By reducing the time spent on non-value-added movements, the runner is no longer fully occupied with transport tasks throughout the entire shift. This creates the possibility to allocate part of the available time to additional activities that support the overall efficiency of the plant.

In particular, the recovered time can be used for:

- supporting logistics and shipping operations, especially during peak workload periods
- managing urgent or non-standard requests that cannot be integrated into the standard milk-run cycle

This contributes to a more flexible and responsive organization, where resources can be allocated dynamically based on operational needs.

At the same time, the adoption of a standardized route reduces variability between shifts and improves coordination between production and logistics. The workflow becomes more predictable, and material supply is less dependent on individual requests and operator experience.

5.4.3 Economic consideration

The time reduction estimated in Section 5.4.1 can be translated into an economic benefit by considering the improved utilization of labor.

Assuming a reduction of approximately 30% of the time required to perform internal logistics activities, the corresponding time saving can be evaluated on a full shift basis.

Given an 8-hour shift, the estimated time saving is:

$$8 \text{ hours} \times 30\% = 2.4 \text{ hours per shift}$$

Assuming an average labor cost of 23 €/hour, the economic value of the recovered time is:

$$2.4 \text{ hours} \times 23 \text{ €/hour} \approx 55 \text{ € per shift}$$

Considering the total number of shifts per year (780 shifts), the annual economic impact can be estimated as:

$$55 \text{ €} \times 780 \approx 42,900 \text{ € per year}$$

This value represents the benefit associated with a more efficient use of labor, rather than a direct reduction in workforce. The recovered time can be allocated to activities that contribute more directly to the overall performance of the plant.

5.4.4 Final considerations

The analysis confirms that the introduction of a standardized milk-run leads to a substantial improvement in internal logistics efficiency, consistent with the expected benefits of lean logistics systems based on flow stabilization and transport optimization [7], [18]. The reduction in time is not achieved through increased work intensity, but through the elimination of inefficiencies and the optimization of flows.

This result highlights the importance of process organization in logistics systems. Even without introducing automation, a structured approach based on lean principles can generate significant benefits in terms of time, cost, and operational stability.

Furthermore, the results obtained in this section provide a solid basis for the subsequent analysis of automation solutions, as they define a more efficient baseline against which further improvements can be evaluated.

6 Automation Proposal: AGV-Based Internal Logistic

The previous chapters analyzed the internal logistics system of the plant, focusing on warehouse reorganization and the standardization of runner activities. The interventions carried out allowed the transition from an unstructured and experience-based system to a more organized configuration, where storage logic, material allocation, and internal flows are defined according to clear and consistent criteria.

In particular, the introduction of zoning strategies, frequency-based storage allocation, and a structured milk-run contributed to improving the predictability of material handling operations. Internal movements became more regular, search times were reduced, and the interaction between warehouse and production was aligned with actual operational needs.

These improvements established a solid and stable logistics framework. However, the system remains based on manual transport activities, with material handling performed by operators using forklifts and electric stackers. As a result, overall performance is still influenced by execution variability, workload distribution, and the need to balance routine operations with unexpected requests.

In this context, automation is not intended as a corrective action, but as a further step in the evolution of the internal logistics system. The objective is to build on the structured configuration already achieved and introduce a transport system capable of supporting material flows in a more consistent and controlled way.

This chapter presents a proposal for the implementation of an Automated Guided Vehicle (AGV) system for internal material transport, building on the increasing maturity of automation solutions for internal logistics [19]. The solution considered is based on a real feasibility study developed in collaboration with STILL, and specifically focuses on the adoption of the AXV 12 iGo vehicle [20].

Although classified as an AGV, this solution integrates advanced navigation technologies that allow it to operate autonomously within the plant. Thanks to the iGo automation framework, and in particular the iGo easy configuration, the vehicle does not require fixed guidance systems such as magnetic tracks or physical references on the floor. Instead, it is capable of navigating within the environment with a level of flexibility comparable to autonomous mobile robots.

The following sections will first provide an overview of automation technologies in internal logistics, and then focus on the technical feasibility, economic evaluation, and potential impact of introducing this system within the plant.

6.1 Little insight into automation

The automation of internal logistics has become increasingly relevant in modern manufacturing environments, particularly in sectors characterized by high production volumes and strong requirements in terms of flow continuity and operational efficiency. In this context, the reduction of non-value-added activities and the stabilization of material handling processes represent key objectives, leading many companies to introduce automated transport systems within their plants.

Among the available technologies, two main categories can be identified: Automated Guided Vehicles (AGVs) and Autonomous Mobile Robots (AMRs), which represent the main technological approaches currently used for automated internal transport [19]. Both systems are designed to automate horizontal material transport, but they differ in terms of navigation logic, flexibility, and adaptability to changing environments.

AGVs represent the most established solution and have traditionally been used in structured and repetitive contexts. Their operation is typically based on predefined routes, which can be defined through physical guides or virtual paths. This makes them particularly suitable for environments where material flows are stable and well defined. The main advantage of AGVs lies in their reliability and consistency, as they follow fixed routes with high precision and ensure repeatable execution of transport tasks.

On the other hand, AMRs have been developed to operate in more dynamic and less structured environments. These systems are capable of navigating autonomously within the plant, adapting their routes in real time, and avoiding obstacles without relying on fixed guidance systems. This allows a higher level of flexibility, making AMRs particularly suitable for applications where layouts, production volumes, or material flows are subject to frequent changes.

Despite this distinction, the technological evolution of internal logistics systems has progressively reduced the gap between AGVs and AMRs. Modern AGV solutions increasingly integrate advanced navigation and control technologies that enable a more flexible and autonomous behavior compared to traditional systems.

This evolution is particularly relevant in the context of industrial applications, where a balance between reliability and flexibility is often required. Instead of choosing between a fully rigid system and a fully dynamic one, current technologies allow the implementation of solutions that combine the advantages of both approaches.

Within this framework, the STILL iGo automation platform represents an example of this evolution, offering scalable automation solutions ranging from simple plug-and-play applications to more integrated systems [20]. The system offers different levels of automation, ranging from assisted driving to fully automated solutions.

In particular, configurations based on iGo easy enable automated vehicles to operate without the need for physical guidance systems, allowing navigation within the plant through onboard intelligence and environmental recognition.

From an operational point of view, this means that AGVs equipped with such technologies can achieve a level of autonomy comparable to that of AMRs, while maintaining the robustness and reliability typical of traditional automated guided systems. This aspect is particularly important in manufacturing environments where flows are repetitive but still subject to a certain degree of variability.

Current automated transport systems are used to support a wide range of internal logistics activities, including the supply of materials to production lines, the movement of semi-finished components between departments, the transport of finished goods to shipping areas, and the handling of empty containers and waste. This reflects a transition from isolated transport operations to a more integrated and continuous management of internal material flows.

Another key aspect of the current state of the art is the integration of automated vehicles with higher-level control systems. Fleet management platforms allow the coordination of multiple vehicles, the assignment of transport missions, and the optimization of routes based on real-time conditions. This enables a more synchronized interaction between logistics and production processes.

Safety and interaction with operators also play a central role in the deployment of these systems. Modern automated vehicles are equipped with sensors and safety devices that allow them to operate in shared environments, adapting their behavior according to surrounding conditions and ensuring safe coexistence with human operators and manual equipment.

Overall, internal logistics automation has reached a level of maturity that allows its application not only in highly standardized environments, but also in contexts where flexibility and adaptability are required. In such scenarios, the availability of hybrid solutions—combining structured transport logic with autonomous navigation capabilities—represents a key enabling factor.

In the case analyzed in this thesis, the adoption of an AGV system equipped with advanced navigation technologies, such as the STILL AXV 12 iGo, represents a coherent evolution of the improvements previously implemented. The system is designed to support internal logistics flows in a more consistent and controlled way, while maintaining the level of flexibility required by the production environment.

6.2 Technical Feasibility Analysis

The technical feasibility of the proposed automation system was evaluated considering the specific characteristics of the plant layout, internal logistics flows, and operational constraints identified in the previous chapters.

The objective of this analysis is to assess whether the selected AGV solution can be effectively integrated within the existing environment, without requiring significant structural modifications, while ensuring reliable and efficient material handling.

The following sections present the main technical choices made during the study, including the selection of the vehicle, the definition of the operating area, and the identification of the system boundaries and operational logic.

6.2.1 AGV Selection and System Definition

The automated solution selected for the feasibility analysis is the STILL AXV 12 iGo, an automated guided vehicle specifically designed for internal pallet transport. The choice of this system is closely related to its ability to operate in environments characterized by mixed traffic conditions, where human operators, forklifts, and manual handling equipment coexist.



Figure 6.1 – STILL AXV 12 iGo

The vehicle operates within the STILL iGo automation framework, and in particular through the iGo easy configuration, which enables a high level of autonomy without the need for fixed guidance infrastructure. Unlike traditional AGVs, which require magnetic tracks or embedded systems, the AXV 12 iGo navigates using a combination of laser scanners, cameras, and advanced localization algorithms, supported by a digital map of the environment previously created during the setup phase.

The system continuously monitors its surroundings, detecting obstacles and dynamically adjusting its trajectory and speed. This allows the AGV to operate safely in shared environments, interacting with operators moving on foot, forklifts, and pallet trucks. In this context, the technology used enables a level of flexibility comparable to that of autonomous mobile robots, while maintaining the robustness of a guided system.

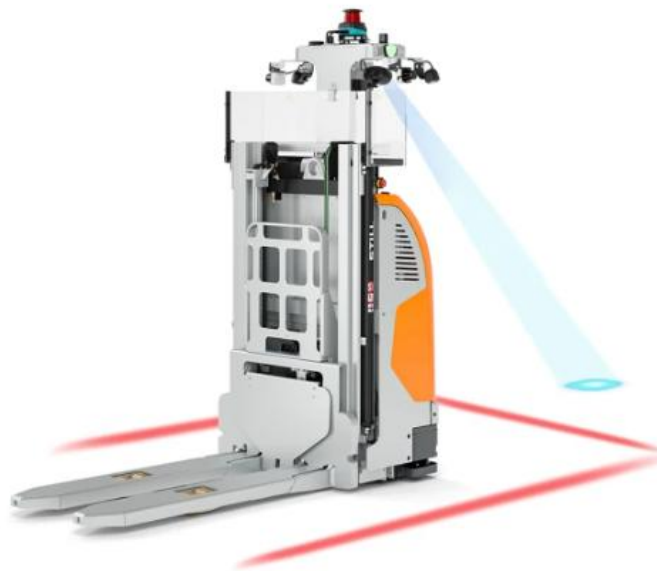


Figure 6.2 – Security system

From an infrastructure point of view, the implementation of this solution does not require significant modifications to the plant. The only additional elements needed are reflective markers, installed in specific positions to support localization and improve navigation accuracy. These elements work in combination with onboard sensors and do not impose rigid constraints on the vehicle's movement.

6.2.2 System Dimensioning and Operational Logic

Based on the analysis of internal material flows and machine activity the system was dimensioned considering the use of a single AGV.

Although the workload during the first shift is relatively high, it remains compatible with the capacity of one vehicle. In addition, during this shift, the presence of logistics operators and team leaders ensures that any exceptional situations or urgent requests can be managed manually if necessary.

During the second and third shifts, the overall workload is significantly lower. Under these conditions, the AGV is able to manage the required logistics activities autonomously, without the need for additional resources. This configuration allows the system to be implemented with a limited initial investment while maintaining operational flexibility.

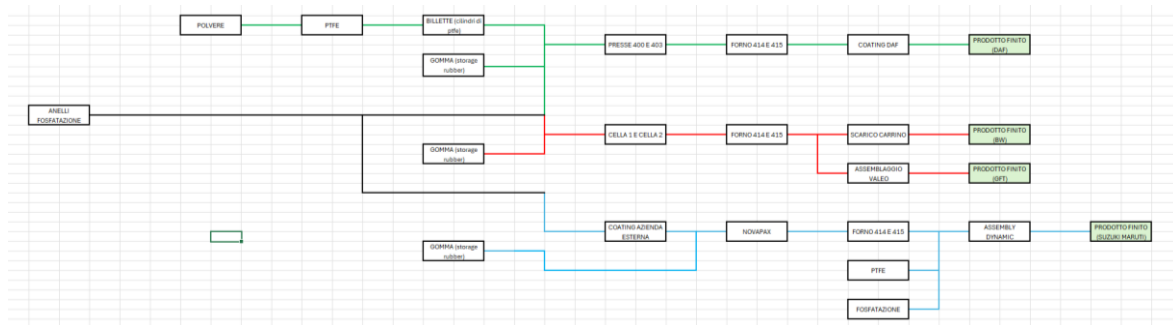


Figure 6.3 – Example of internal material flow in Unipiston department

6.2.3 Definition of the Operating Area

The AGV operating area was defined based on the analysis of the plant layout and internal traffic conditions. The mapping was intentionally limited to specific zones of the plant, corresponding to areas where the circulation of handling equipment is already allowed and structurally supported.

This choice was driven by two main considerations. First, only routes compatible with vehicle circulation were included, ensuring safe and efficient navigation without requiring modifications to existing pathways. Second, the analysis of machine activity frequency highlighted that some workstations are characterized by very low utilization during the year. Including these areas in the automated system would not generate significant benefits and would unnecessarily increase complexity.

As shown in Figure 6.4, the layout highlights the different functional areas defined for the AGV implementation.

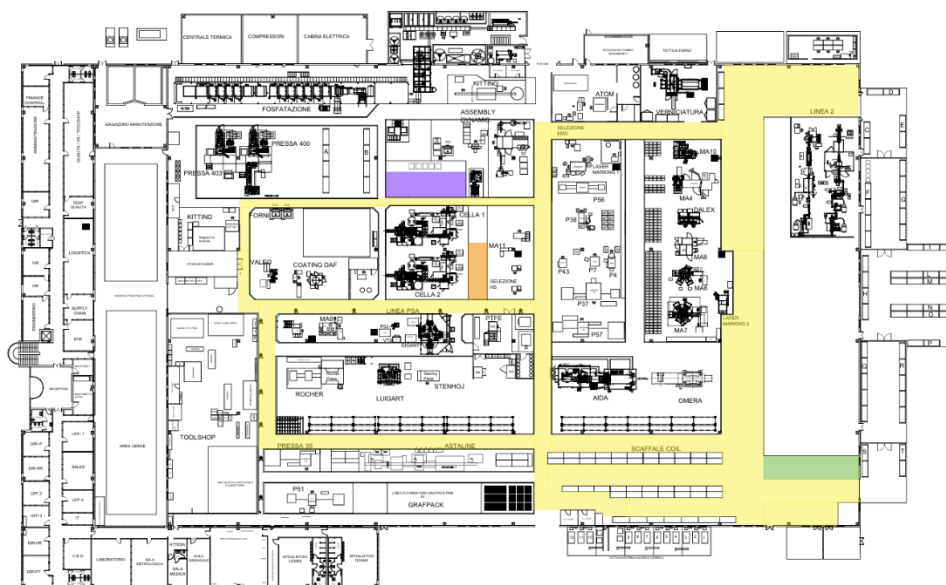


Figure 6.4 – Operating area

The yellow area represents the main operating zone of the AGV. This area has been designed to ensure coverage of all the machines included in the automation scope, allowing the vehicle to perform material handling activities along predefined and accessible routes. The selected paths follow the existing circulation corridors, minimizing interference with manual operations and ensuring continuity of movement.

The green area is defined as the loading and unloading zone. In this area, pallets transported by the AGV are deposited and temporarily stored. From this point, logistics operators are responsible for allocating the pallets to the appropriate storage locations, depending on their content (finished goods, packaging materials, or work-in-progress).

This separation between transport and storage activities allows the AGV to focus exclusively on horizontal movement, improving overall system efficiency.

The purple area is designated as the charging station of the AGV. This position has been selected to ensure accessibility from the main operating routes while minimizing interference with production and logistics activities. The location allows the vehicle to recharge during idle periods without affecting the continuity of operations.

The orange area represents a buffer zone used for exceptional or overflow situations. This area is intended for pallets deposited manually by operators or team leaders when the AGV is temporarily unavailable or already engaged in other tasks. It is also used for handling materials coming from machines that are not included in the automated route, such as specific presses or low-frequency workstations.

In these cases, pallets can be placed in this shared area and subsequently collected by the AGV when available, ensuring integration between automated and manual logistics flows.

6.2.4 Scope Limitation and Exclusion of Advanced AGV Functions

During the feasibility analysis, the option of adopting an AGV capable of automatic storage and retrieval from warehouse racks was also considered. However, this solution was excluded due to several technical and operational constraints.

The warehouse area is characterized by high traffic levels, especially during the first two shifts, as it is used for both inbound and outbound logistics operations. Introducing an automated system in this zone would significantly increase the complexity of traffic management and could generate interference between manual and automated flows.

From an economic perspective, this type of solution would require higher investment, which is not justified by the actual needs of the plant. Storage operations can be efficiently managed by existing personnel without creating bottlenecks in the process.

Additional constraints are related to the physical characteristics of the warehouse. Differences in floor conditions would require structural modifications to ensure reliable AGV operation, leading to increased costs without proportional benefits. Moreover, temperature variations between indoor and outdoor areas could negatively affect the system's performance and durability, particularly during winter conditions.

Moreover, the presence of fire doors separating production and warehouse areas would require the implementation of dedicated sensor systems to ensure automatic opening during AGV transit, further increasing system complexity.

For these reasons, the proposed solution focuses exclusively on horizontal transport between predefined points, leaving storage operations to manual handling.

6.2.5 Operating Logic and System Interaction

From an operational point of view, the AGV system is based on a set of predefined loading and unloading positions, as shown in Figure X. These positions represent fixed points within the plant where materials are picked up or delivered.

Transport missions are generated through a dedicated software interface, accessible directly by operators and team leaders through tablets. This allows requests to be issued without the need to physically move from the workstation, improving responsiveness and reducing unnecessary movements.

Once a mission is generated, the AGV is able to execute a sequence of operations autonomously, moving between different points according to the assigned tasks. The system is designed to handle multiple missions in sequence, optimizing movements and ensuring efficient use of the vehicle.

The implementation of this system also requires a certain level of standardization in load units. In particular, the use of standardized pallets is necessary to ensure compatibility with the AGV's handling system and to guarantee reliable loading and unloading operations.

The combination of predefined positions, digital mission management, and autonomous execution allows the system to integrate effectively with the existing logistics structure, supporting the material flow without disrupting current operations.

6.3 Cost Analysis

The economic evaluation of the proposed automation solution is based on a comparison between the investment required for the AGV implementation and the current cost associated with manual internal logistics operations.

6.3.1 Initial investment cost

The total investment required for the implementation of the automated system is estimated at:

$$150,000 \text{ €}$$

This value includes the supply of the vehicle, system installation, mapping of the operating environment, and software configuration. As discussed in the previous section, no significant structural modifications to the plant are required, which allows the investment to remain relatively contained compared to more complex automation solutions.

6.3.2 AGV operating and maintenance cost

In addition to the initial investment, it is necessary to consider the annual operating costs associated with the AGV system. Among these, maintenance represents the most relevant component.

Based on industry benchmarks, the annual maintenance cost of an AGV system is typically estimated between 5% and 10% of the vehicle purchase cost, depending on the level of service, system complexity, and usage intensity.

Considering the selected solution and a moderate level of system complexity, a conservative estimation can be defined as follows:

Annual maintenance cost (estimated):

$$150,000 \text{ €} \times 7\% = 10,500 \text{ € per year}$$

This value includes:

- preventive maintenance activities
- software updates and system adjustments
- technical support from the supplier
- minor spare parts replacement

In addition to maintenance, the AGV system may generate limited additional operating costs, such as:

- energy consumption (electric charging)
- periodic system calibration
- potential software service agreements

However, these costs are generally marginal compared to both labor cost and the overall investment.

6.3.3 Current labor cost

In the current configuration, internal material handling activities are performed by a dedicated operator assigned to each shift. Given the three-shift production system, this results in a total of three operators per day, each covering an 8-hour working period.

The economic evaluation of this configuration is based on a set of operational assumptions, summarized in Table 6.1.

Parameter	Value
Hourly labor cost	23 €/hour
Working time per shift	8 hours
Number of shifts per day	3
Working days per week	5
Total shifts per year	780

Table 6.1 – Labor cost

6.3.3.1 Direct labor costs

Based on these parameters, the direct labor cost can be calculated starting from the cost associated with a single shift and then extended to a yearly basis.

The cost per shift is equal to:

$$8 \text{ hours} \times 23 \text{ €/hour} = 184 \text{ €}$$

Considering the total number of shifts performed annually, the direct labor cost results in:

$$184 \text{ €} \times 780 \text{ shifts} = 143,520 \text{ € per year}$$

While this value represents the direct cost associated with labor, it does not fully capture the overall economic impact of employing dedicated personnel for internal logistics activities.

6.3.3.2 Indirect labor costs

In addition to direct wages, the presence of operators introduces a series of indirect costs that must be considered to obtain a more realistic evaluation. These include, among others, training activities, paid leave, absenteeism, and the natural variability in performance between different operators. Furthermore, coordination and supervision activities also contribute to the overall cost of the system.

Rather than estimating each of these elements separately, it is common practice to account for them through a correction factor applied to the direct labor cost. In industrial contexts similar to the one analyzed, this factor typically ranges between 20% and 25%.

Applying this adjustment, the total annual cost associated with manual internal logistics operations can be estimated as follows:

Cost component	Value
Direct labor cost	143,520 €
Indirect costs (20–25%)	28,500 – 36,000 €
Total annual cost	≈ 172,000 – 180,000 €

Table 6.2 – Indirect labor cost

For the purpose of this analysis, a reference value of:

175,000 € per year

will be considered as the total cost associated with the current manual system.

6.3.4 Cost comparison

Once the annual cost of the current manual system and the estimated maintenance cost of the automated solution have been defined, it is possible to compare the two configurations from an economic point of view.

Table 6.3 summarizes the main cost elements considered in the comparison.

Item	Cost
Manual system (annual cost)	175,000 €
AGV system (initial investment)	150,000 €
AGV system (annual maintenance)	10,500 €

Table 6.3 – Cost comparison

From a purely annual operating perspective, the automated solution is characterized by a much lower recurring cost than the manual system. Once installed, the AGV mainly generates maintenance and service-related expenses, while the manual configuration requires the continuous availability of operators across three shifts.

For this reason, the annual economic benefit of the automated solution can be estimated as the difference between the annual cost of the current manual system and the annual maintenance cost of the AGV:

$$\text{Annual net saving} = 175,000 \text{ €} - 10,500 \text{ €} = 164,500 \text{ € / year}$$

This value represents the theoretical yearly benefit generated once the system is fully operational.

6.3.4.1 Payback period

Based on the annual net saving calculated above, the payback period can be estimated by comparing the initial investment with the expected yearly saving:

$$\text{Payback} = 150,000 \text{ €} / 164,500 \text{ €} \approx 0.91 \text{ years}$$

$$\text{Payback} \approx 11 \text{ months}$$

6.3.4.2 Three-year cost comparison

In order to provide a more complete view of the investment, it is useful to extend the analysis over a medium-term horizon. A three-year comparison allows a better understanding of the cumulative economic impact of the two alternatives.

In a first approximation, assuming constant costs, the total cost of the manual system over three years would be:

$$175,000 \text{ €} \times 3 = 525,000 \text{ €}$$

However, in order to provide a more realistic evaluation, the impact of inflation on labor cost has been considered. Assuming an average annual inflation rate of 2.5%, the cost associated with manual operations increases progressively over time.

In contrast, the automated system is characterized by a significantly lower exposure to inflation, as its main cost component is the initial investment, while annual maintenance costs remain relatively stable.

The updated comparison is summarized in Table 6.4

Configuration	Year 1	Year 2	Year 3	Total over 3 years
Manual system	175,000 €	179,375 €	183,859 €	538,234 €
AGV system	160,500 €	10,500 €	10,500 €	181,500 €

Table 6.4 – Three years cost comparison

It is important to note that, in the first year, the AGV cost includes both the initial investment and the first year of maintenance. Even under this condition, the total first-year cost remains below the yearly cost of the current manual system.

Over a three-year period, the overall saving generated by the automated solution can therefore be estimated as:

$$538,234 \text{ €} - 181,500 \text{ €} \approx 356,700 \text{ €}$$

This result shows that the economic advantage of the automated solution is not limited to the payback period, but becomes increasingly significant over time. Once the investment has been recovered, the difference between the two systems is mainly driven by the gap between labor cost and annual maintenance cost, further amplified by the effect of inflation.

6.3.5 Considerations

The economic analysis carried out in this section highlights a clear advantage of the proposed automated solution compared to the current manual configuration, in line with the benefits commonly associated with AGV implementation in manufacturing logistics [21]. The results show that the investment required for the implementation of the AGV system can be recovered within a relatively short time, with a payback period of approximately eleven months.

From an operational perspective, the comparison between the two configurations is strongly influenced by the structure of labor costs. The need to guarantee continuous material supply across three shifts leads to a significant annual cost, which represents the main driver behind the economic convenience of the automated solution. In contrast, the AGV system is characterized by a high initial investment but relatively low recurring costs, mainly associated with maintenance.

The extension of the analysis over a three-year time horizon further reinforces this conclusion. The cumulative cost comparison shows that the automated solution generates substantial savings over time, with an economic advantage that increases progressively. This effect is amplified when considering the impact of inflation, which mainly affects labor costs and has a limited influence on the automated system.

It is important to underline that the present evaluation is based on a simplified model that considers the AGV as a direct substitute for manual transport activities. In practice, the introduction of the automated system does not necessarily eliminate the need for human

intervention, but rather modifies the role of operators within the logistics process. The AGV can take over repetitive and low value-added transport tasks, while operators can be reallocated to activities requiring higher flexibility and decision-making capabilities.

In addition to the direct economic benefits, the implementation of the AGV system is expected to contribute to a more stable and predictable management of internal logistics flows. The reduction of variability between shifts, the standardization of transport activities, and the improved coordination between production and logistics represent additional advantages that are not fully captured by the purely economic analysis.

Finally, it is worth noting that the results obtained are based on conservative assumptions. Even when considering potential variations in labor cost, maintenance expenses, or system utilization, the overall economic balance remains favorable to the automated solution. This confirms that the proposed investment represents a robust and sustainable improvement for the internal logistics system, both from an operational and a financial perspective.

6.4 Risk and Organizational Impact

The implementation of an automated internal logistics system introduces both technical and organizational implications that must be carefully evaluated to ensure a smooth and effective transition from the current manual configuration.

From a technical perspective, one of the main aspects to consider is the integration of the AGV within a dynamic production environment. The plant is characterized by the simultaneous presence of operators, forklifts, and manual handling equipment, particularly during the first shift, where logistics activities are more intense. Although the selected system is designed to operate safely in shared environments, the coexistence of automated and manual flows requires the definition of clear operating rules, especially in critical areas such as intersections, loading and unloading zones, and high-traffic paths.

Another relevant aspect concerns system reliability. As the AGV becomes an integral part of the internal supply process, potential downtimes or technical malfunctions could affect the continuity of material flow toward production. For this reason, it is necessary to maintain a certain level of operational flexibility, ensuring that operators or team leaders are able to temporarily manage critical activities when required. The current organization already supports this approach, as personnel in the logistics area can intervene in case of exceptional situations.

From an organizational point of view, the introduction of the AGV does not eliminate the need for human resources, but rather enables a structural redefinition of roles within the plant. In the current configuration, the runner is mainly engaged in repetitive transport activities, often characterized by a high incidence of non-value-added movements.

With the introduction of the automated system, these activities can be largely absorbed by the AGV, allowing the gradual replacement of the runner role as it currently exists. The personnel previously assigned to this function can be reassigned to roles that directly contribute to the production process or to logistics activities with higher operational relevance.

In particular, depending on their skills and experience, operators can be reallocated as:

- production operators on machines, providing direct support to manufacturing activities and contributing to value creation
- logistics or shipping operators, supporting pallet completion, material organization, and outbound flow management

This transition represents a shift from a transport-oriented role to functions that generate direct value within the process. Rather than simply supporting production through material handling, operators become actively involved in core activities, improving both productivity and resource utilization.

This approach also increases operational flexibility, as personnel can be allocated dynamically based on production needs, reducing dependency on a single dedicated role and enabling a more balanced distribution of workload across the plant.

Another important aspect concerns change management. The transition from a manual to a partially automated system may initially generate resistance among operators, especially if the new process is perceived as less flexible or more structured. For this reason, it is essential to involve personnel during the implementation phase, providing adequate training and clearly communicating the objectives of the project. A gradual introduction of the system, supported by a transition phase in which manual and automated activities coexist, can facilitate adaptation and reduce potential disruptions.

From a process perspective, the introduction of the AGV contributes to a higher level of standardization in internal logistics. The definition of predefined routes, structured loading and unloading points, and digitalized call systems reduces variability and improves the predictability of material flows. At the same time, this increased level of structure requires consistent adherence to defined procedures, which must be maintained over time to fully exploit the benefits of the system.

Finally, it is important to underline that the proposed solution has been designed with a targeted scope of automation, focusing on the areas and machines with the highest operational frequency. This approach allows limiting implementation complexity and associated risks, while preserving the flexibility required to manage less frequent activities through manual intervention.

At the time of writing, the proposed solution is not only theoretical but is currently under evaluation within the company, in collaboration with the selected supplier. The project is actively progressing, and its implementation is expected to be completed by the end of the year.

This confirms the practical relevance of the proposed approach and its alignment with the company's ongoing strategy for the improvement of internal logistics processes.

Overall, the introduction of the AGV represents a progressive evolution of the current internal logistics system rather than a disruptive change. While some risks related to system integration and organizational adaptation are present, they can be effectively mitigated through proper planning, training, and gradual implementation. At the same time, the expected impact on the organization is largely positive, as it enables a more efficient allocation of resources and supports a more structured and stable management of internal material flows.

7 Conclusion

The work developed throughout this thesis focused on the analysis and improvement of internal logistics flows within the Chivasso plant, with the objective of increasing operational efficiency and reducing non-value-added activities.

The study was structured into three main phases. The first phase concerned the analysis and reorganization of the warehouse layout and material handling processes. This intervention has already been implemented within the plant and has led to a more rational use of space and a significant reduction in material search times, generating a direct and measurable economic benefit.

The second phase focused on the analysis and standardization of runner activities through the introduction of a milk-run system. This solution is currently in use and has improved the management of internal logistics flows by reducing unnecessary movements, limiting empty travel, and introducing a more structured and predictable workflow. The time analysis confirmed a reduction of approximately 30% in the execution time of logistics activities, with a positive impact on both efficiency and resource utilization.

The final phase explored the potential introduction of an automated solution based on an AGV system. Unlike the previous interventions, this solution has not yet been implemented but is currently under evaluation within the company, in collaboration with the selected supplier. The project is actively progressing, and its implementation is expected by the end of the year. The analysis carried out demonstrated that automation represents a feasible and economically advantageous evolution of the current system, capable of further improving internal logistics performance and supporting a more efficient allocation of human resources.

7.1 Economic summary

The economic impact of the proposed improvements is summarized in Table 7.1.

Intervention	Annual Benefit (€)	Type of Benefit	Main Driver
Warehouse reorganization	~24,000 €	Direct cost saving	Reduction of material search time
Milk-run implementation	~40,000 – 43,000 €	Productivity improvement	Reduction of non-value-added movements (~30%)
AGV implementation	~160,000 €	Labor cost avoidance	Automation of transport activities

Table 7.1 – Total saving after the application of the three projects

7.2 Total estimated impact

Considering the combined contribution of all interventions:

Total annual benefit $\approx$ 220,000 €

It is important to underline that these results are not generated by isolated actions, but by a structured and progressive approach. In particular, the effectiveness of the automated solution is strongly enabled by the prior reorganization of the layout and the standardization of internal logistics processes.

7.3 Final remarks

The results obtained demonstrate how significant improvements can be achieved through a systematic approach based on analysis, process redesign, and gradual introduction of advanced technologies. The project highlights that the optimization of internal logistics does not rely solely on automation, but requires a solid foundation built on organization, standardization, and flow control.

From this perspective, the work carried out does not represent a final solution, but rather a scalable model that can be further extended and refined over time.

The integration of lean principles with automation technologies represents a key factor for the future development of efficient and flexible manufacturing systems, where human and automated resources operate in a complementary and value-oriented way.

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