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Optimization of Material Handling Process

Kuehne + Nagel Case Study

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List of Abbreviations

All acronyms and abbreviations used in this thesis are listed in the following table.

Acronym	**Meaning**
ABC	Activity-Based Classification (used for warehouse item categorization)
AGV	Automated Guided Vehicle
AMR	Autonomous Mobile Robot
AS-IS	Current state of the process
CDR	Centro Distribuzione Ricambi (Spare Parts Ditribution Center, in Turin)
CT	Cycle Time
CT_{th}	Theoretical Cycle Time
DIR	Delivery Inaccuracy Rate
DMAIC	Define-Measure-Analyze-Improve-Control (Lean Six Sigma methodology)
E	Tugger Trin Efficiency
FCL	Full Container Load
FMEA	Failure Mode and Effects Analysis
FTL	Full Truck Load
JIT	Just-inTime
KPI	Key Performance Indicator
LCL	Less-than-Container Load
LTL	Less-than-Truck Load
NVA	Non-Value-Added activity
NVAN	Non-Value-Added but Necessary activity
P&P	Pick & Pack (warehouse area dedicated to picking and packing)
PIR	Picking Intensity Ratio
PN	Part Number (unique item identification code)
PT	Process Time
SCOR	Supply Chain Operations Reference (model)
TO-BE	Future State of the process
T_w	Waiting Time
$T_{u/l}$	Waiting Time for loading/unloading activities
UDR	Unit Delivery Reference – internal handling unit handling unit within the warehouse. In this study, the term is also used in the form “Macro UDR”, referring to a specific functional area of the warehouse.
VA	Value-Added activity

VSM	Value Stream Mapping
WMS	Warehouse Management System

1. Introduction

This thesis was developed within the spare parts warehouse of Iveco Group in Turin, managed by the logistics operator Kuehne+Nagel. It presents the study and development of a project aimed at optimizing the internal material handling process between departments and functional areas. The project is part of the company's long-standing continuous improvement initiatives, which represent a strategic pillar for enhancing operational efficiency and increasing the value delivered to customers.

From a methodological perspective, the study adopted the DMAIC (Define–Measure–Analyze–Improve–Control) approach, which enabled a systematic analysis of the process in its current configuration (AS-IS), the identification of major inefficiencies, and the related root causes, in order to design targeted improvement solutions. Some of the proposed solutions were actually implemented during the development of this thesis, allowing their impact to be measured through the analysis of the corresponding KPIs (Key Performance Indicators) in the TO-BE (Future State) situation. The remaining solutions are still in the study and design phase; therefore, the thesis reports only their conceptual development and the expected results.
The impact of the interventions effectively implemented was assessed through a comparison of performance indicators in the initial and future configurations, demonstrating a reduction in inefficiencies within the analyzed material handling process.

The thesis is structured in an initial theoretical framework, introducing the role of logistics warehouses, the main performance indicators, and methodological approaches for process optimization. This is followed by the case study description, with a focus on the layout and operational flows of the Turin warehouse. The core section of the thesis presents the continuous improvement project, including the analysis of the process and its inefficiencies, the related root causes and the proposed solutions, with an evaluation of the achieved benefits. Finally, it will be presented a reflection on future perspectives regarding both the implementation of pending solutions and additional opportunities for process enhancement.

2. Description of a Warehouse: Functions, Types, and Key Performance Indicators

2.1. Definition and Role

A warehouse plays a crucial role in supply chain management, serving as a central point for receiving, storing, and distributing goods. Its efficiency can significantly impact a company's operational performance.

In the following paragraphs, we will explore the main functions and roles of a warehouse. We will examine how these functions contribute to the continuous flow of materials and products through the logistics network.

2.1.1. Definition and Main Functions

A warehouse is a facility used for the storage and handling of goods, and it is an essential component of the supply chain.

According to Faveto et al., the main processes carried out within a warehouse are *receiving*, *transfer* and *storing*, *accumulation*, *sortation*, *order picking*, *cross-docking*, and *shipping*. The warehouse management involves processes like the assignment of trucks to the docks, the planning of loading and unloading activities, and the allocation of resources for material handling. Moreover, the warehouse can be divided into different departments and zones, in order to optimize storage efficiency and material handling process.

Firstly, goods arrive to a warehouse in a carrier and are unloaded at the receiving docks. Later they are loaded into a carrier and leave the warehouse through the shipping docks. For cross-docking warehouses, received goods are sent directly from the receiving docks to the shipping docks. For traditional warehouses that hold inventory, received goods are put away into storage (Gu J. et al., 2006). When customers' orders are received, goods are retrieved and sorted/assembled for shipments. Finally, the complete orders are shipped to customers. Understanding these fundamental processes within a warehouse sets the stage for exploring the strategic role that warehouses play in the broader context of supply chain management.

2.1.2. Strategic Role in the Supply Chain

A supply chain consists of all flows and transformations from simple raw materials to purchase of end-items by consumers.

To describe the supply chain operations needed to fulfill consumer demand it is possible to use the SCOR model (Supply Chain Operations Reference). This model describes the six basic processes as follows: planning, sourcing, making, delivering, returning, and enabling. Within each of these processes, some sub-processes and tasks are industry and organization-specific (Huan et al., 2004).

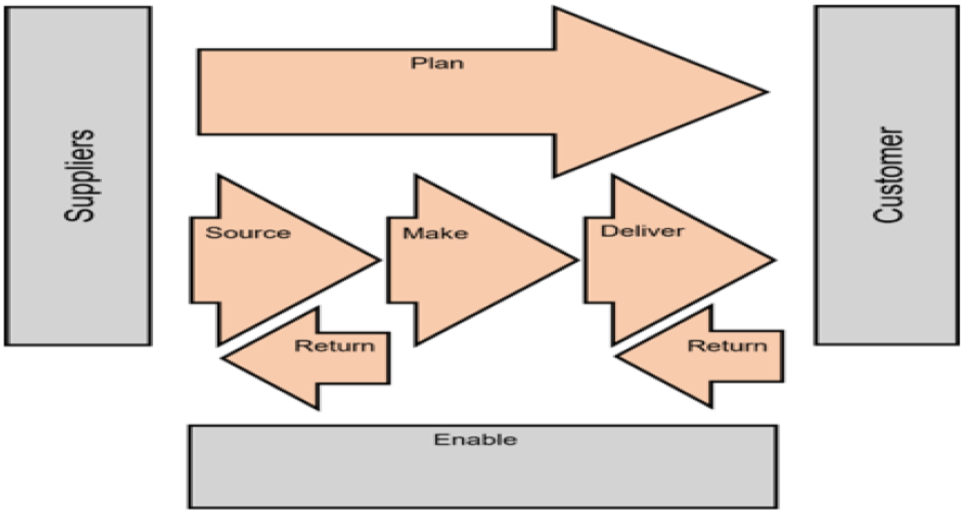

Figure 1: Supply chain operations reference (SCOR) model (Archie & Kevin, 2004)

In addition, we can stand that inside a supply chain various network nodes perform component fabrication, product assembly or sales. These activities, however, require logistical support, e.g., storage of intermediate or finished goods; consolidation of orders; and transportation (Higginson et al., 2005). In this context, warehouses play a crucial role, functioning as distribution centers. Distribution centers can be of various types, such as the following:

- ***Make-break/bulk centers:*** these centers consolidate customers orders in one single delivery to obtain transport economies;
- ***Cross-docking centers:*** orders of customers cross these centers within few hours or days;
- ***Transshipment facilities:*** they are used to change transport mode (for example from transportation vehicles with big dimensions to ones with lower dimensions);

- ***Assembly facilities:*** in these plants products can be sorted and assembled according to the final configuration required by the client;
- ***Product-fulfilment centers:*** These centers directly address the product orders from final customers, such as those received through internet fulfilment operations;
- ***Depots to manage returned goods:*** they receive unwanted and damaged goods, handle the process of reaccepting products into the warehouse, and manage exchanges/returns for customers;

All these warehouse's roles are listed inside the article "An exploratory framework of the role of inventory and warehousing in international supply chains", written by Peter Baker and published in the International Journal of Logistics Management in 2007.

Given the crucial role that warehouses play in the supply chain, it is essential to have effective warehouse management that oversees processes from start to finish, ensuring the timely and efficient delivery of items (Richards, 2022). Efficient warehouse management enhances supply chain processing, improves product organization, and boosts operational efficiency.

To ensure the efficiency of warehouse operations, robust logistics management is also necessary. Logistics management is a comprehensive strategy that integrates and manages the flow of information and materials from suppliers to the marketplace, ensuring that all parts of the supply chain work together to meet consumer needs (Christopher, 2005). The figure below illustrates the activities that contribute to providing value to consumers through the supply chain.

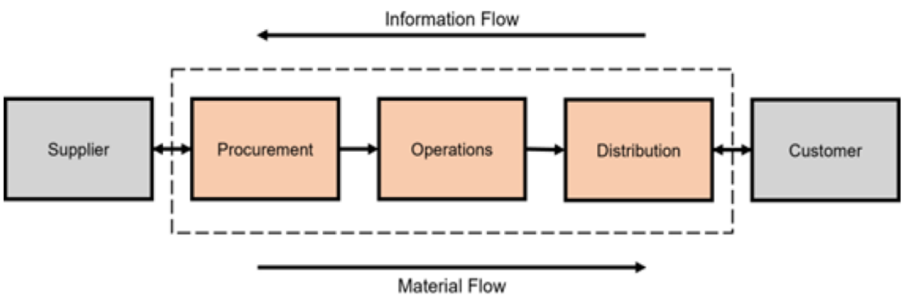

Figure 2: Logistics Mangament (Christopher, 2005)

After outlining the functions and strategic role of warehouses within the supply chain, it becomes essential to classify the different types of warehouses, with particular attention to the distinction between storage warehouses and logistics warehouses, as well as between traditional and automated systems. This distinction is crucial for understanding the design and operational choices that directly impact the overall efficiency and responsiveness of the entire supply chain.

2.2. Warehouse Types

After outlining the functions and strategic role of warehouses within the supply chain, it becomes essential to classify the different types of warehouses, with particular attention to the distinction between storage warehouses and logistics warehouses, as well as between traditional and automated systems. This distinction is crucial for understanding the design and operational choices that directly impact the overall efficiency and responsiveness of the entire supply chain.

2.2.1. Logistic Warehouse vs. Storage Warehouse

Logistics and storage warehouses have generally the same strategic relevance, functioning as crucial nodes within the distribution network. However, despite this similar characteristic, they have substantial different objectives and operational configurations.

The primary function of storage warehouses is to retain stock for medium to long periods, without performing value-adding activities. These warehouses represent essentially buffers between production and final demand, and typically act in contexts characterized by stable, predictable demand and low inventory turnover.

In contrast, logistics warehouses play a much more dynamic role, directly contributing to customer service levels, and they are often defined as distribution centers. As noted by Baker and Canessa (2009), these warehouses perform a wide range of functions within the supply chain, including order consolidation, cross-docking, and various value-added services such as product labelling, postponed assembly, and returns management.

The integration of these multiple roles makes logistics warehouses highly complex facilities. Indeed, Baker (2004) highlights that such warehouses are often designed to guarantee extremely short order fulfillment times, including same-day or next-day deliveries—a sharp contrast to storage warehouses, where the focus is primarily on storage capacity rather than speed or responsiveness.

In conclusion, while storage warehouses serve a passive and stock-conserving function, logistics warehouses take on an active role in value creation, enabling synchronized flows and requiring efficient design of internal operations. The warehouse analyzed in this case study perfectly embodies the characteristics of a logistics warehouse, combining multiple interconnected operations to effectively meet final customer requirements.

2.2.2. Comparison between Traditional and Automated Warehouses

In today's world, where automation has become an integral part of our daily lives, it is also important to compare traditional warehouses with automated warehouses. The former rely primarily on manual operations for receiving, storing, and shipping goods. In this case, warehouse workers—assisted by specific equipment such as forklifts, handheld scanners, and other tools—carry out most of the warehouse activities. For this reason, traditional warehouses are considered labor-intensive facilities, often subject to human error and with limited ability to adapt to demand peaks or to increased needs for operational flexibility (Odeyinka & Omoegun, 2023).

On the other hand, automated warehouses integrate advanced technologies such as ASRS (Automated Storage and Retrieval Systems), Autonomous Mobile Robots (AMRs), Automated Guided Vehicle (AGVs), IoT sensors, and various tools for digital warehouse management. These solutions enable more efficient space utilization, faster picking times, higher accuracy, and continuous operations—often 24/7 (Kamali, 2019). According to Kamali (2019), automation not only boosts productivity but also generates significant economies of scale, improving customer service levels and flow traceability.

As noted by Odeyinka and Omoegun (2023), the choice between a traditional and an automated warehouse depends on several factors, including volume of operations, availability of labor, expected service level, and the company's long-term strategic vision.

As we will see in the case study presented in this thesis, the warehouse under analysis—initially designed as a traditional facility—has undergone several transformations over the past 20 years, moving gradually toward automation in order to increase internal productivity and efficiency. In the description of the warehouse in the following sections, we will observe a hybrid model, combining traditional and automated elements. In fact, some areas of the warehouse have recently been equipped with automated racking systems integrated with autonomous robots (AGVs), used to manage specific materials and product flows. Furthermore, one of the proposed solutions within this project involves the application of AMR technology, confirming a clear trend toward continuous innovation and automation in the warehouse's operational model.

2.3. Operational Areas and Flows

A warehouse is a dynamic environment composed of multiple operational zones and interconnected material flows. These areas are organized to facilitate a continuous transition from goods receipt to customer shipment, optimizing internal efficiency while minimizing delays, errors, and unnecessary movements. A clear understanding of how these areas are structured and interact is essential for designing and managing high-performing warehouse systems.

2.3.1. Layout and Zoning

According to Faveto et al. (2023), a typical warehouse layout can be divided into several functional zones: the inbound area**,** where goods are received and checked; the storage area**,** which accommodates either short- or long-term stock; the order picking or fulfillment area**,** where items are collected to fulfill customer orders; and the outbound area**,** dedicated to packaging and shipping operations. (Faveto, A., Traini, E., Bruno, G. *et al.* Review-based method for evaluating key performance indicators: an application on warehouse system. 2024)

Each zone plays a distinct role within the warehouse workflow. For example, the storage area must balance space efficiency with accessibility, while the picking area is typically designed to minimize travel distance and handling time. These zones must be carefully coordinated to ensure continuous and accurate material flow, which is especially critical in high-throughput environments.

2.3.2. Material Handling and Optimization Strategies

Material handling connects the different areas of the warehouse, and the choice of handling systems, manual or automated, directly affects the warehouse's responsiveness and cost efficiency. As highlighted by Gu et al. (2007), the design of material handling strategies depends on factors such as order profiles, product characteristics, and throughput levels Optimization techniques, including zoning, slotting, and the application of performance metrics like picking accuracy or inventory turnover, can effectively enhance operational outcomes. For instance, integrated Warehouse Management Systems (WMS) and real-time monitoring can support the identification of bottlenecks and guide decisions for layout reconfiguration or process improvement (Faveto et al., 2023).

2.4. Performance Indicators

In the context of warehouse management, Key Performance Indicators (KPIs) serve as essential tools for measuring, monitoring, and improving operational efficiency and effectiveness. These indicators enable logistics managers to make data-driven decisions by identifying bottlenecks, waste, and improvement opportunities across warehouse processes. As highlighted by Chakma (2024), the implementation of specific KPIs allows organizations not only to benchmark performance over time or across facilities but also to align operational outcomes with strategic goals, ultimately enhancing the company's overall competitiveness.

2.4.1. KPIs for Monitoring Logistic Warehouse Performance

To improve the overall efficiency of the logistics system it is crucial evaluating warehouse performance. To achieve this result, it is necessary to identify and define Key Performance Indicators (KPIs) that measure the efficiency of processes inside the warehouse (Chakma, 2024). With the concept of “Lean Warehousing” companies start focusing on maximizing efficiency and productivity while minimizing waste and non-value-added activities (Faveto et al., 2023). The first step to achieve this is to set the right KPIs to measure and monitor. The use of indicators is, in fact, strictly linked to three different aims: to assess the current status of a process, to continuously monitor the progress of a particular process in a specific time frame, and to evaluate the impact of a particular strategy or change.

According to Faveto, key performance indicators can be categorized into three clusters, based on economic aspects, environmental aspects, and social aspects. The most important cluster is the first mentioned (that is also the biggest one) and it is the one that will be mainly treated in this study.

The KPIs of the economic cluster indicate the warehouse’s performances that directly affects the company’s costs and profit. Inside this group it is possible to subdivide the indicators into four different subcategories: generic performances, time-related performances, cost-related performances, and ICT performances. In this project the focus will be mainly on the first two categories, which includes the KPIs reported in Table 1 below. Moreover, it can be useful also to assess and define some specific indicators related to material handling, which are described in the literature. Vuong (2020), for instance, identifies a series of critical KPIs that are particularly relevant for evaluating operational effectiveness in material handling processes. These indicators, reported in Table 1, allow for a clear assessment of how materials are moved, stored, and prepared within the warehouse.

Not all the indicators described below will be applied in practice in this study, because of the complexity and diversity of operations in the real logistic processes under analysis. For this reason, only some of these indicators (such as the Resource utilization, Travel Distance, Handling Cycle Time, and Travel Time) will be utilized in this study to assess and optimize the processes examined within the project. They will be reviewed and adapted to the specific context, taking into account the operational requirements and the practical conditions of the warehouse.

These indicators will be presented in Chapter 5, within the measuring phase of the project development. In this chapter, they will be referenced and adapted, with a detailed explanation of their application as well as their adjustment to the practical context of the project.

Cluster	KPI	Definition	Reference
Generic Performances	Bottleneck rate	Maximum reachable system throughput	*"Review-based Method for Evaluating Key Performance Indicators: An Application on Warehouse Systems*", authored by Faveto et al.
	Picking Accuracy	Measures the percentage of items picked correctly during a time shift	
	Receptivity	Total number of load units that can be stored in the warehouse (storage capacity)	
	Resource Utilization	% of the time in which resources (humans, vehicles, etc.) perform operations	
	Travel Distance	Total distance travelled by the piker or the vehicle to move between the input/output point of the warehouse to the storage/retrieval point located in the warehouse	
Time-related Performances	Cycle Time	Total time required to complete a loading/unloading operation	
	Lead time	Time the intercurrent between the order received by the supplier and to order arrival at the retail location	
	Travel Time	Total time needed by the piker or the vehicle to move between the warehouse's input/output point to the storage/retrieval point located in the warehouse	
	Task Time	Time required to complete a grasping operation on a given shelf	
Material Handling Performances	Handling Cycle Time	Total time required to complete a full handling operation from start to finish	*"Monitoring and managing KPIs of material handling performance in operative logistics"*, authored by Vuong et al.
	Material Movement Rate	Number of items moved within a given time period, indicating process speed and flow efficiency	
	Order Picking Accuracy	Accuracy and speed of order picking tasks, directly impacting service quality,	
	Warehouse Space Utilization	% of available storage area used	

Table 1: Logistic Warehouse KPIs

3. Lean Production Methodology

In recent years, the increasing competitiveness of global markets has led companies to implement more effective methods to optimize their production and logistics processes. In this context, Lean Production has emerged as one of the most widely adopted methodologies for improving operational efficiency, minimizing waste, and maximizing customer value.

This section provides an overview of the fundamental principles of Lean Production, starting from reporting its historical development and presenting key tools used for process improvement, with a focus on the impact of Lean principles on logistics and warehouse operations, which represent a core application area in the present study.

Lean Production is a philosophy that originated in Japan, primarily developed through the Toyota Production System. Its core aim is to eliminate waste (Muda), reduce production lead times, and increase efficiency through continuous improvement. The goal is to create more value for the customer using less resources, improving quality while reducing costs (Masuti et al., 2019).

3.1. History and Evolution of the Lean Manufacturing

Lean Manufacturing has its roots in the post-World War II era, when Japanese manufacturers needed to produce efficiently in a context of limited resources. The term “lean” was coined in the 1990s by Womack and Jones, who studied Toyota’s system and identified its core principles: value, value stream, flow, pull, and perfection.

Over time, lean evolved from a production model into a philosophy applicable across various sectors, including services and logistics. Recent studies (Purushothaman et al., 2020) show that lean has been successfully adapted to multicultural and complex environments, maintaining its effectiveness in reducing waste and improving performance.

3.2. Key Lean Tools for Process Optimization

Some of the most widely used lean tools include:

- **Value Stream Mapping (VSM)**: A visual tool used to map the current and future states of a process, identifying value-added and non-value-added activities (Masuti & Dabade, 2019).
- **5S**: A method for organizing and standardizing the workplace to improve efficiency and safety.
- **Kaizen**: A structured approach to continuous improvement, often implemented through focused improvement events.

- **Just-in-Time (JIT)**: A production strategy that aligns output with actual demand, reducing inventory and lead times.
- **Poka-Yoke**: Error-proofing mechanisms designed to prevent defects.
- **Kanban**: A visual system for managing material flow and production scheduling.

The implementation of these tools has been shown to significantly reduce cycle times, waste, and operational costs (Purushothaman et al., 2020; Masuti et al., 2019).

3.3. Impact of Lean Principles on Logistic and Warehouse Efficiency

Applying lean principles in logistics and warehouse operations has led to tangible improvements in efficiency, flexibility, and service quality. According to Purushothaman et al. (2020), lean tools have helped reduce waiting times, improve space utilization, and increase productivity, even in multicultural workplaces.

In particular, the integration of lean with process innovation has been shown to enhance overall operational performance. Möldner et al. (2020) found that both technical and human lean practices positively influence incremental and radical process innovation, which in turn improves key performance indicators such as cost, speed, flexibility, and quality.

In the following chapters, the integration of lean ideology in the logistics environment will be explained and demonstrated through the implementation of the same project that is the object of this thesis.

4. Case Kuehne-Nagel: Iveco Warehouse in Turin

4.1. Company Overview

Kuehne + Nagel International AG (o *Kühne + Nagel*) is a global company specialized in logistics services. It was founded in 1890, by August Kühne and Friedrich Nagel in Bremen, Germany. Today, the company has its headquarter in Schindellegi (Switzerland). it operates through more than 1,300 offices, employing approximately 81,000 people across nearly 100 countries worldwide.

Its activities are structured around four main business units (Figure 3): Sea Logistics, Air Logistics, Road Logistics, and Contract Logistics.

- **Sea Logistics** provides services such as Full Container Load (FCL) and Less-than-Container Load (LCL) shipments, as well as specialized options including refrigerated transport and oversized cargo handling.
- **Air Logistics** offers flexible air transport solutions through three service levels (Express, Expert, Extend), allowing customers to balance speed and cost depending on their needs. Additional services include charter flights, time-critical solutions, and combined sea-air transport.
- **Road Logistics** manages freight transportation by road at both national and international levels, covering Full Truck Load (FTL), Less-than-Truck Load (LTL), and groupage services to ensure efficient door-to-door connections across Europe and beyond.
- **Contract Logistics** includes end-to-end solutions, such as warehousing, distribution, and in-house logistics management. These services are customized based on the specific industry of application, like automotive, high-tech, pharmaceuticals, retail, and industrial sectors. They involve value-added activities such as packaging, inventory management, e-commerce support, and aftermarket logistics.

Figure 3: Kuehne + Nagel Business Units

4.1.1. Production System Team and the Continuous Improvement in Kuehne+Nagel

Nel contest della contract logistic, che ha quindi lo scopo di offrire la gestione delle operation all'interno del magazzino, ormai da diversi anni è nato il Production System. This team has been established inside the company framework in order to to drive **Continuous Improvement** throughout the business by delivering value to **Customers and Operations.** The approach and ideology of the Production System is to continuously support and develop the growth of employees' capabilities in problem solving and process optimization. continuously improving processes dealing with logistics variation.

Its purpose is, in fact, to ensure that logistics processes are continuously improved to effectively address variability and inefficiencies.

The Production System is structured around four key and interconnected pillars, defined as the "*infrastructure for continuous improvement*":

- **Lean Leadership** for establishing strategic alignment by ensuring that efforts are directed toward the actual needs of customers.
- **Value Stream Improvement** for addressing performance gaps through the deployment of appropriate Lean tools and methods, such as Flow & Pull, Stability, Standard Work, Visual Management, and 5S.
- **Operational Management** for ensuring stability and continuous improvement by removing obstacles and pursuing operational excellence in every activity.
- **Continuous Improvement Focus & Lean Behaviour** for developing problem-solving capabilities by building skilled teams and nurturing a culture of Lean thinking at all organizational levels.

Production System plays a central role in developing projects and improvement activities within the company, by providing a structured Lean framework that guides problem identification, analysis, and solution design. Through its four pillars, it ensures that initiatives are consistently aligned with Lean principles, such as waste elimination, process stability, and value creation for the customer. In practice, this means that improvement projects are carried out following standardized Lean methodologies, such as process mapping, root cause analysis, and the application of tools like Flow & Pull, 5S, and Visual Management. As a result, the Production System not only drives operational excellence but also enables the systematic implementation of Lean projects across different business units and warehouses, including the case study analyzed in this thesis.

4.2. The Warehouse

The Kuehne + Nagel warehouse in Turin is owned by Iveco Group, a multinational automotive company specializing in commercial and specialty vehicles, propulsion systems, and related financial services. Iveco Group's legal headquarters are in Amsterdam, while its main headquarters are in Turin. Kuehne + Nagel manages the logistics of three warehouses across Europe, including locations in Turin (Italy), Azuqueca (Spain), and Langenau (Germany). Among these, the Turin site is the most significant, handling 156,000 different items, and serving markets in Italy, Europe, and non-EU countries.

Kuehne + Nagel manages Receiving, Packaging, Storage, Picking, Packing, and Shipping for Iveco Group, offering services related to Quality, Logistic Engineering, Continuous Improvement, System Management, and Productivity Measurement.

(Sgro, M., 2023, Analysis of the new automated warehouse installed at the IVECO spare parts facility (Turin), managed by logistics operator KUEHNE+ NAGEL (PhD Thesis). Politecnico di Torino)

4.2.1. Layout and Warehouse Overview

The warehouse located in Turin was built in 1950 and covers a total area of approximately 190,000 m². It can store around 250,000 pallets, and the number of employees is approximately 600.

The facility includes a significant number of departments, each dedicated to different processes. Figure 4 represents all these processes to provide a clear overview; but the analysis focuses on the areas relevant to the study, without going into excessive detail for each process.

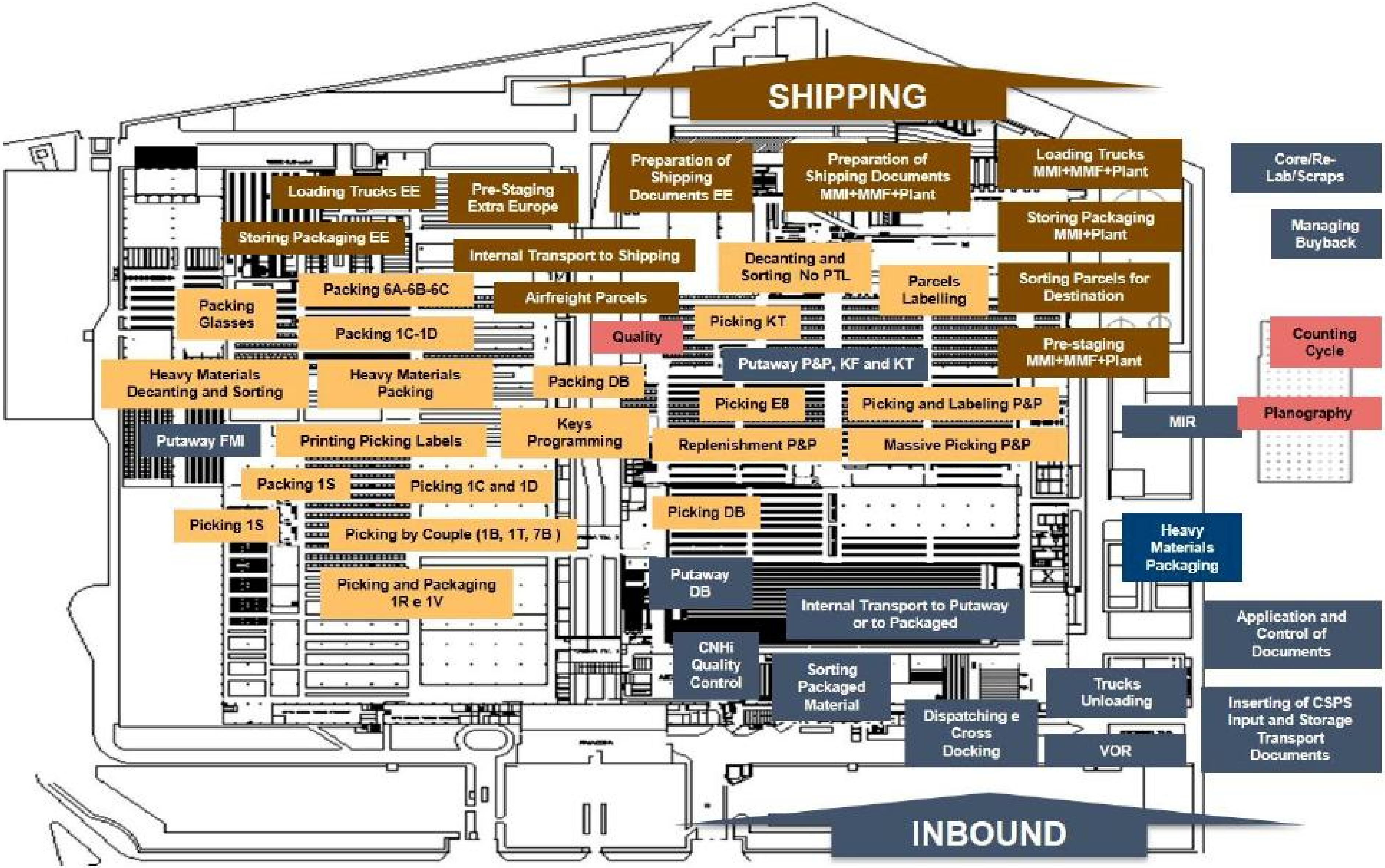

Figure 4: Turin Warehouse Layout and Processes (Sgro, 2023)

4.2.2. Macro areas and macro-flows

Kuehne+Nagel Turin Warehouse is divided into different operational areas, classified into four macro-areas: Inbound, Outbound, Shipping, and External areas (reported in Figure 5).

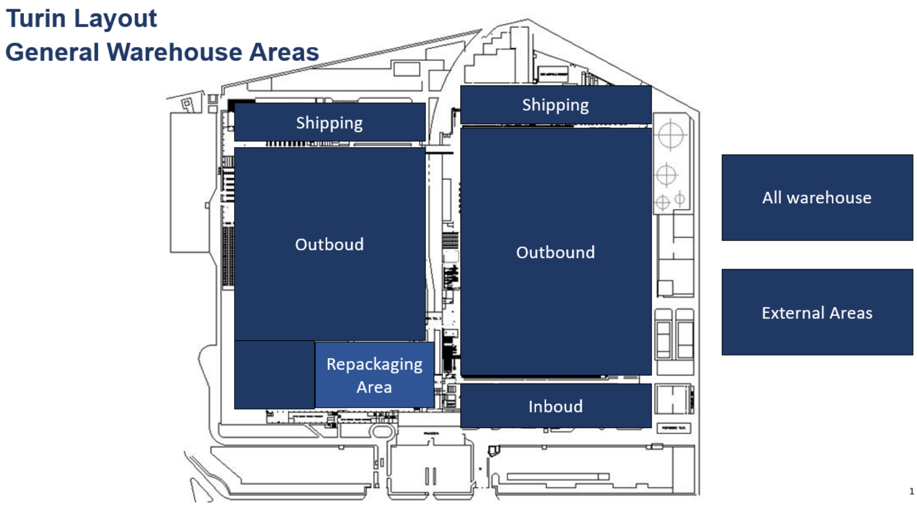

Figure 5: Macro-areas layout (Sgro, 2023)

Across these areas materials follow a specific flow, based on product type, handling class, and the specific operations to be performed (Sgro, M., 2023, Analysis of the new automated warehouse installed at the IVECO spare parts facility (Turin), managed by logistics operator KUEHNE+ NAGEL. Politecnico di Torino). The overall material flow can be categorized into three main macro-flows, as follows:

- ***Storage Flow →*** Materials arriving from other Iveco plants or third-party suppliers are received in the **Inbound** department. These materials can be categorized into different types: they may already be packaged, they may require packaging before being stored, or they may be managed through cross-docking, where the goods bypass storage and go directly to the shipping department for dispatch to customers. For the first category, the next step is *Putaway*, while for the second category, the materials are first moved to a dedicated repackaging area managed by an external cooperative and then stored in the warehouse.

  Each item is stored in a specific warehouse zone selected based on its handling class and physical characteristics.

- ***Outflow:***
  Material stored in the **Outbound** department continue the flow with the picking phase, where the materials are retrieved and subsequently packed in the dedicated packing area in preparation for movement to the shipping department.
- ***Shipping Flow:***
  Material picked and packed from the different warehouse zones is moved to the **Shipping** department, where it is sorted and prepared for final shipment to the customer.

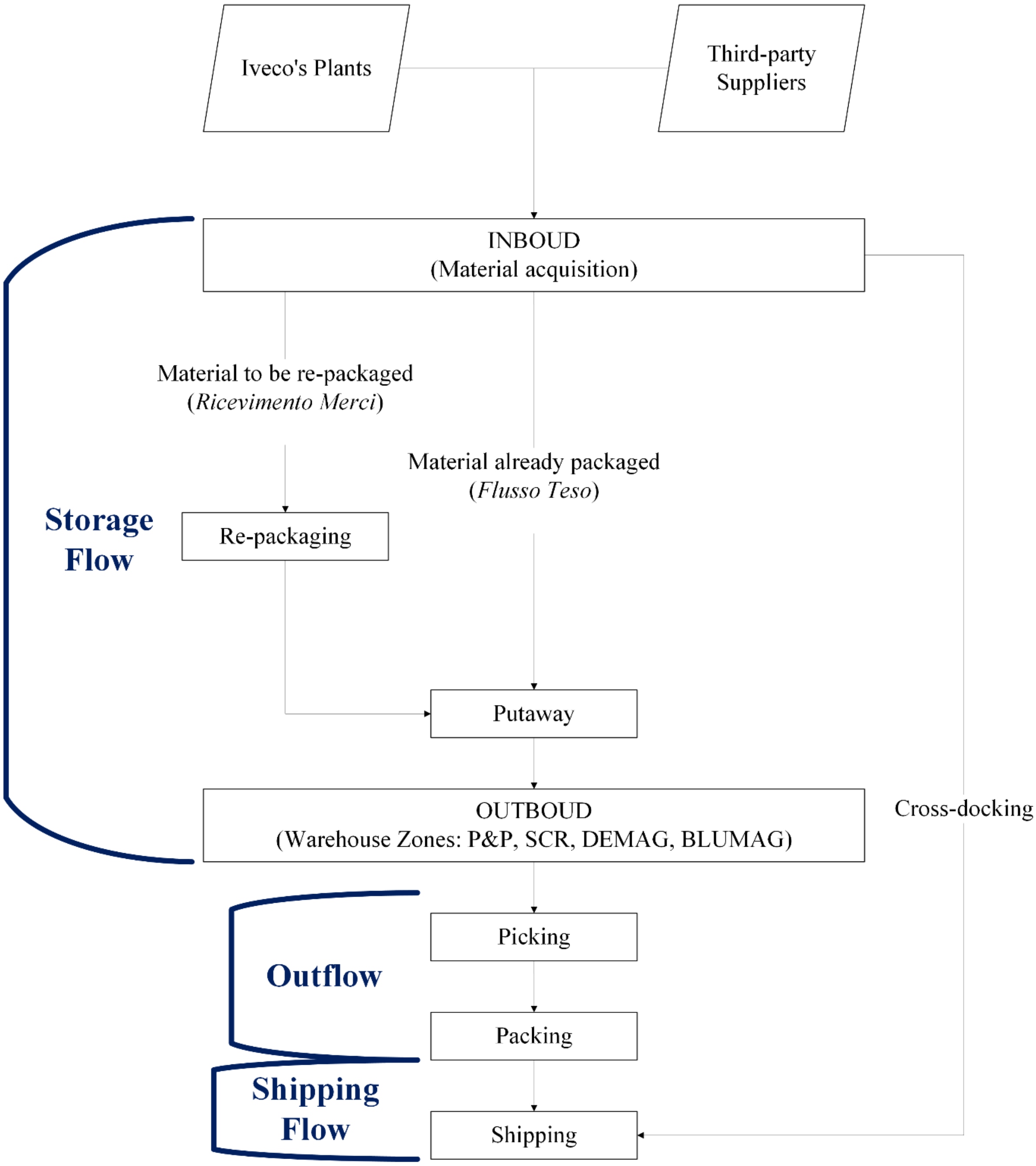

Figure 6: Flow Chart - Material Flow inside the warehouse

The Outboud department is located within two main buildings, known as SCR and CDR. The latter includes the PICK & PACK, DEMAG, and BLUMAG warehouses. These zones are reported in the Figure 7.

Figure 7: Warehouse Zones - Turin Layout (Sgro, 2023)

Each of these zones is further divided into sub-zones, each with specific names and characteristics, as reported in Figure 8.

In this study we will focus only on some of these areas, according to the objective of the project.

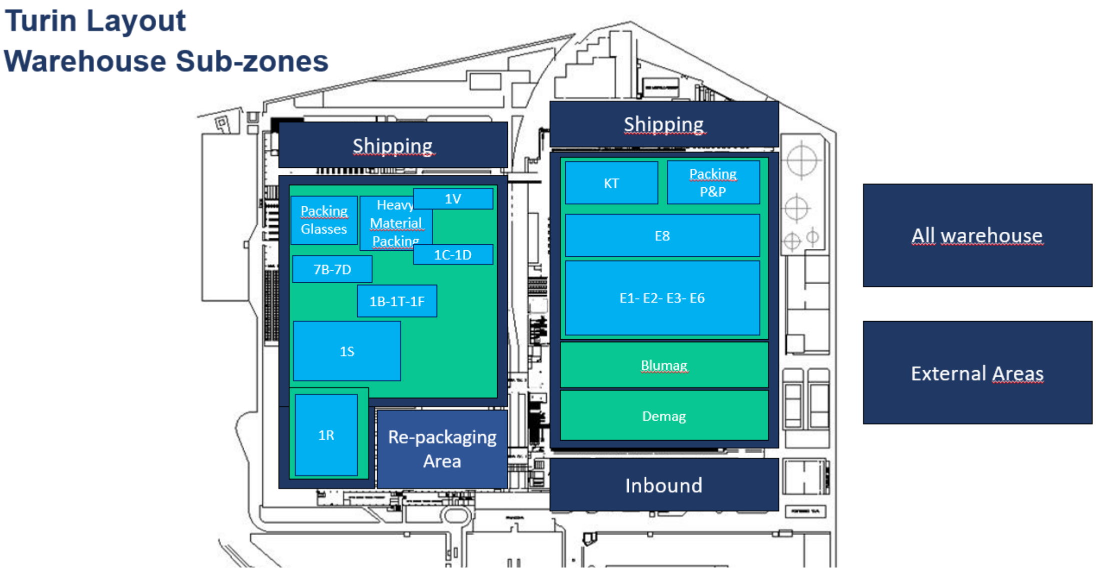

Figure 8: Warehouse Sub-zones - Turin Layout (Sgro, 2023)

4.2.3. Operational Flows and Internal Management

Building on the previous section, which outlined the three main macro-flows—Storage flow, Outflow, and Shipping flow— this paragraph focuses on a detailed analysis of selected operational flows. Specifically, it examines those flows that are most relevant to the scope of this project, with the aim of understanding their structure, sequence of operations, and specific handling requirements.

4.2.3.1. Storage Flow

As mentioned in the previous paragraph, materials arriving from other Iveco plants or third-party suppliers can vary in type. Depending on their characteristics, they follow specific flows within the warehouse. These flows are operationally defined within the warehouse as: *"Flusso Teso"*, *"Ricevimento Merci"*, and *"Cross-docking"*.

<u>Flusso Teso</u>

This is a direct-to-stock flow: the materials received by the Inbound department are already contained in their final packaging (in compliance with customer specifications), allowing them to be stocked directly in the designated warehouse zones without the need for additional packaging/repackaging activity.

Figure 9 provides a graphical representation of the material flow associated with the *Flusso Teso* process.

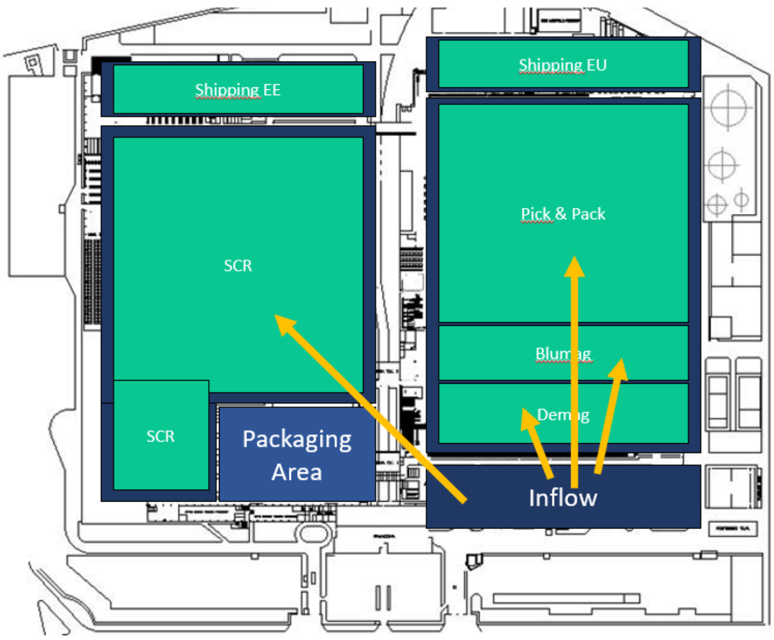

Figure 9: Operational Flow - Flusso Teso

Depending on the specific characteristics of each item, such as weight and volume, materials may be stored using either primary or secondary packaging:

- *Secondary packaging*: Spare parts with low weight and volume are typically delivered in their final packaging, often plastic bags, and are subsequently placed into carton boxes, wire mesh containers or standardized plastic Odette containers (used for the automated shelves) for internal handling and storage within the appropriate warehouse zones. These types of packaging are reported in the following figure 10, 11, and 12.

Figure 10: Odette container (DEMAG) with material to be stored

Figure 11: Odette container (BLUMAG) with material to be stored

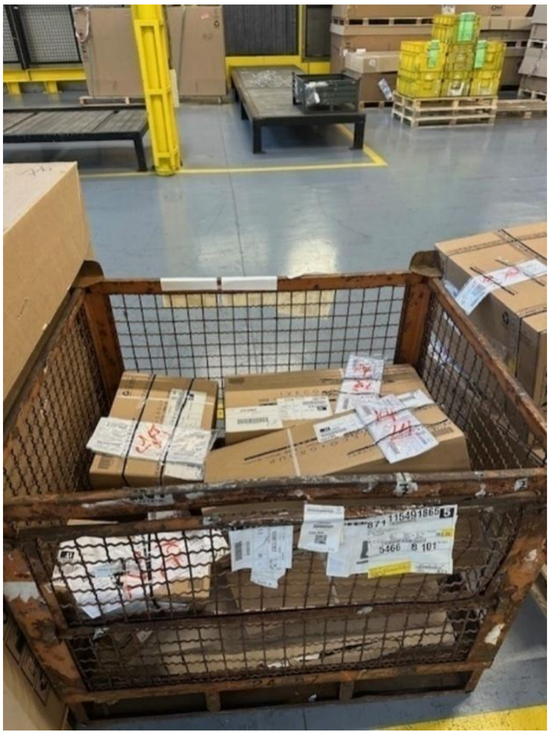

Figure 12: Mesh container with material to be stored

- *Tertiary packaging*: Spare parts with medium to high weight and volume (e.g., engines or windshields) are stored and handled using their final packaging, which generally consists of wooden crates or carton boxes, as shown in figure 13 below.

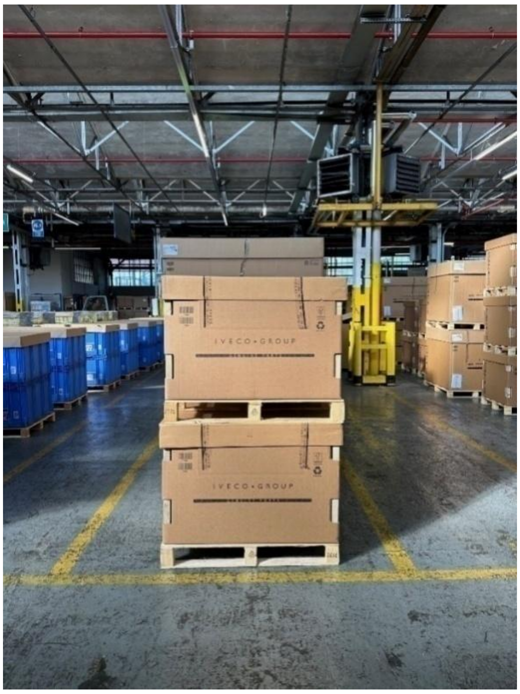

Figure 13: Material stored in carton boxes

The weight and volume of each item not only influence the type of packaging used but also determine the most suitable storage location within the warehouse. Additionally, the handling class of the item plays a key role in the selection of the appropriate storage area. The Paragraph 4.2.4 explains how the warehouse zones are classified according to items rotation class and their physical characteristics.

<u>Ricevimento Merci</u>

This flow is classified as an inbound processing flow, in which materials entering the warehouse require packaging or repackaging operations in accordance with customer specifications before being allocated to storage. Upon arrival at the Inbound department, the materials undergo an initial transfer to a dedicated processing area within the warehouse, where the necessary packaging or repackaging activities are carried out. Once this step is completed, the materials are moved again and directed to the appropriate storage zones. Figure 14 provides a graphical representation of the material flow associated with the *Ricevimento Merci* process.

The selection of the specific storage location follows the same criteria and parameters applied in the previously described direct-to-stock flow (*Flusso Teso*), considering the characteristics of the items.

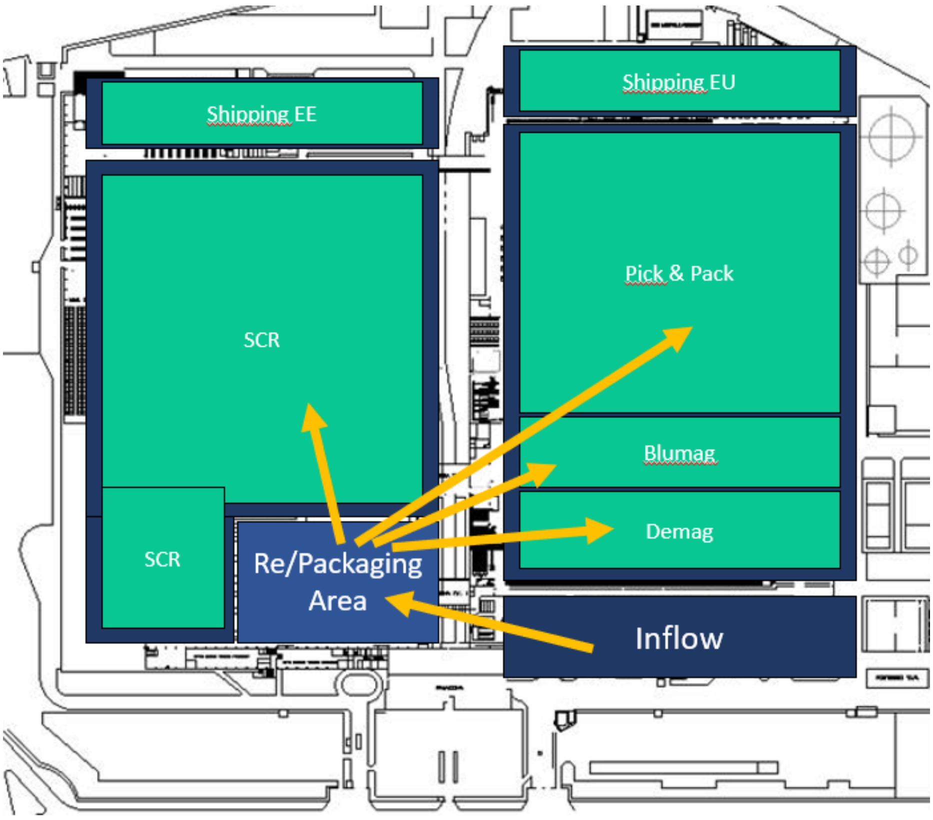

Figure 14: Operational Flow - Ricevimento Merci

Cross-Docking

This process is classified as a bypass flow, in which materials received and registered at the Inbound department are already packaged and do not require storage within the warehouse. As a result, they undergo only the label printing phase—specifically, the generation of the *cartellino collo*, the final label affixed to the goods for shipment to the final customer—before being directly transferred to the Shipping department for dispatching, as illustrated in figure 15.

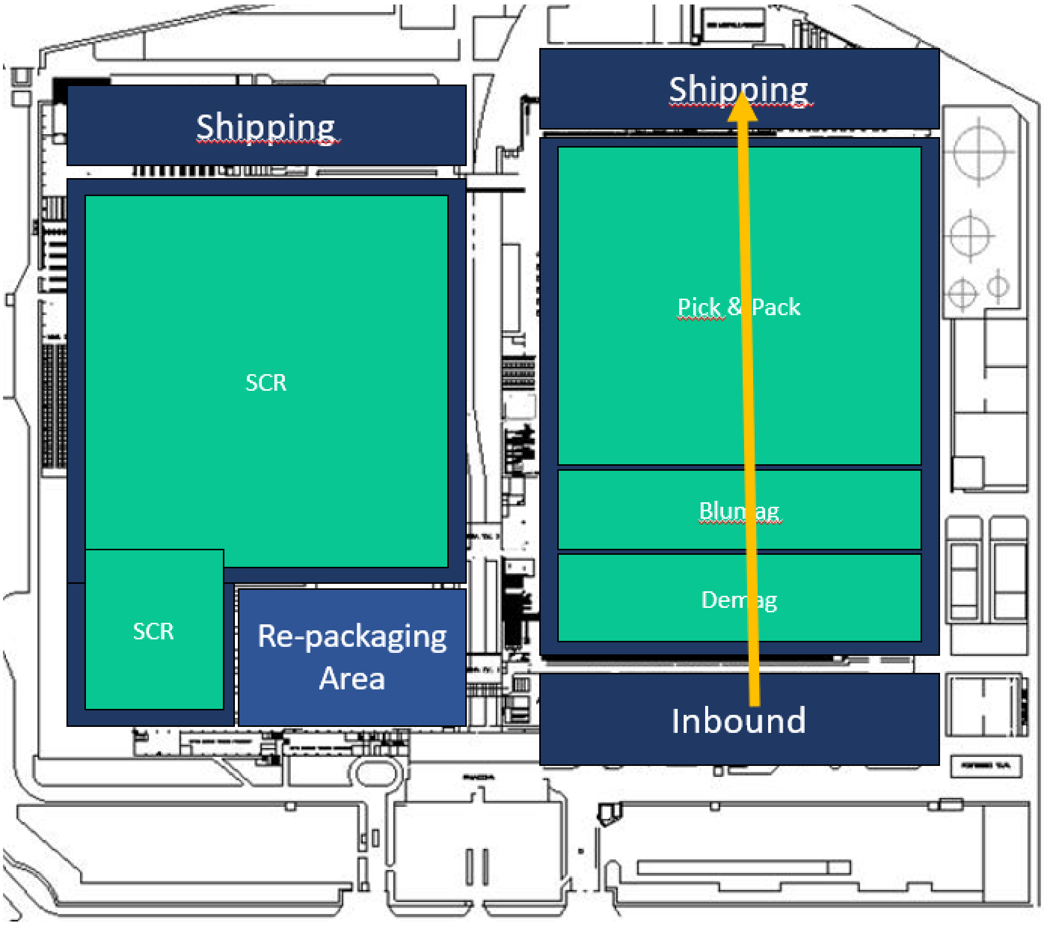

Figure 15: Operational Flow - Cross Docking

Materials in this flow can be handled using two different types of packaging:

- *Tertiary packaging*: used for items with high volume and weight (see Figure 16). These materials undergo only the label printing and application phase before being directly moved to the Shipping department, from which they are dispatched to the customer.

Figure 16: Packaged Material with medium-high volume and weight

- *Secondary or quasi-tertiary packaging*: used for items with lower volume and weight (see Figure 17). These materials are labeled for shipment and then placed into internal handling carton boxes. These boxes, which may include items from different orders or customers, are subsequently transferred to the Shipping department, where sorting and order consolidation activities are performed prior to final dispatch.

Figure 17: Packed Material with low volume and weight, grouped into carton boxes

In all three flows described, the movement of materials is carried out using an internal handling system known as the "Tugger Train", that is a type of logistics train designed to transport goods between different areas within the warehouse. The use of the Tugger Train system for material handling has been specifically highlighted, as this process represents the focus of the present case study. A detailed analysis will be presented in Chapter 6, where the project will be thoroughly described with the aim of identifying potential improvements and optimizations.

4.2.3.2. Outflow

The Outflow process refers to the movement of materials from the various storage areas within the warehouse to the dedicated packing station, where the items picked from the designated zones are prepared for shipment. This includes the application of the final shipping label (*cartellino collo*) and the appropriate packaging operations required for delivery to the end customer.

The packed materials may involve different types of packaging configurations, depending on the nature and characteristics of the items. Specifically:

- *Small boxes grouped into larger carton boxes* (as illustrated in figure 17 above)→ Small and lightweight spare parts are typically packed in their final individual packaging, usually small carton boxes, onto which a shipping label (referred to as *cartellino collo*) is applied. These individual units are then consolidated into larger carton boxes, which serve as secondary or quasi-tertiary packaging, in order to facilitate internal handling and transportation toward the shipping area, where they are subsequently sorted and dispatched to the final customer.
- *Pallet* (shown in figure 18 and 17 below) → Items palletized and then wrapped with stretch film or secured with strapping bands (tertiary packaging).

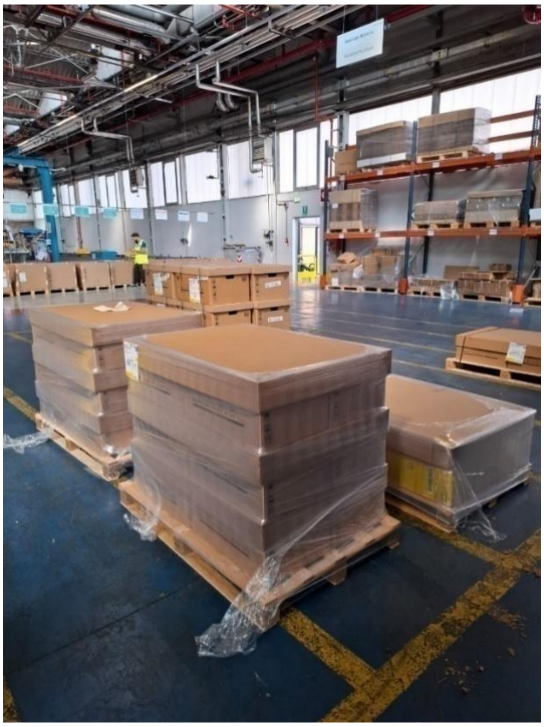

Figure 18: Pallet secured with stretch film

Figure 19: Pallet secured with strapping bands

- *Individual Packaging* (as illustrated in figure 16)→ Spare parts with medium to high weight and volume are packed in their final packaging, such as wooden crates or reinforced cartons. These items are often shipped as standalone units, without being palletized, when their size or handling requirements make it more appropriate.

This variety of packaging solutions reflects the need to adapt the outbound logistics process to the specific physical and logistical characteristics of each item, while ensuring compliance with customer requirements and optimizing the efficiency of the shipping flow.

4.2.3.3. Shipping Flow

The Shipping flow involves the transportation of packed items from each packaging station in the outbound areas to the shipping department, where a final sorting process is carried out, if required, before the goods are dispatched to the customer.
As in the Storage flow, the movement of materials is performed using the internal handling system known as the “Tugger Train”. Chapter 6 will provide a detailed description of this process, in order to explain the context of the project developed in this study.

4.2.4. Warehouse Zoning and ABC Classification of Managed Items

As mentioned in the previous section, the selection of the appropriate warehouse zone for storing a specific item is based on two main criteria: the physical characteristics of the item (weight and volume) and its handling class.

In this paragraph, an analysis is presented at the warehouse zone level, aimed at identifying the general characteristics of the items stored in each area.
Given the large number of items managed within the Iveco warehouse, it was not feasible to conduct an ABC, Activity-Based Classification, and a detailed weight and volume analysis for each individual product.
For this reason, both the ABC classification and the physical characteristics analysis were carried out at a higher and more aggregated level, focusing on warehouse zones rather than on single items.

ABC Analysis

The ABC analysis was conducted based on *picking frequency*, defined as the sum of order lines (i.e., individual order rows placed by a single customer) picked during the year 2024 for each item. Each item, identified by its unique Part Number code, was associated with its corresponding warehouse zone of origin, where it is stored and from which it is picked.

This approach allowed for the aggregation of the total number of picked lines per zone, enabling the execution of the ABC classification at the warehouse zone level.

The resulting classification is illustrated in Figure 20, which shows the Pareto chart representing the ABC distribution of the warehouse zones.

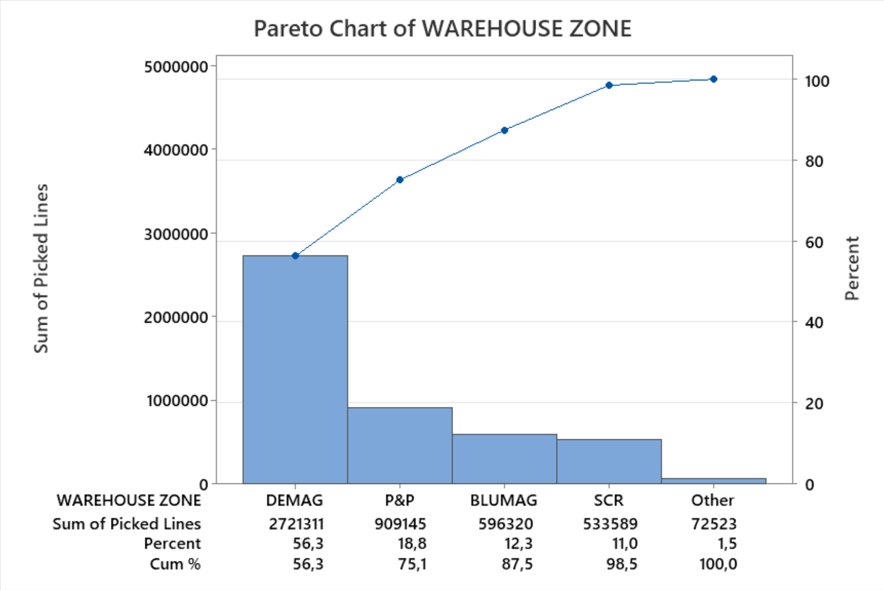

Figure 20: Pareto Chart for ABC Classification for Warehouse Zone

The Pareto chart highlights that the greatest part of picked lines originate from the main warehouse zones, while the remaining zones contribute to a lesser extent. The analysis derived from the chart illustrates the contribution of each warehouse zone in terms of both percentage and absolute number of picked lines during the year 2024, as detailed below:

- **DEMAG**: 2.721.311 picked lines (56.3%)
- **P&P (Pick & Pack):** 909.145 picked lines (18.8%)
- **BLUMAG**: 596.320 picked lines (12.3%)
- **SCR**: 533.589 picked lines (11%)
- **Other**: 72.523 picked lines (3.4%)

From the Pareto analysis, it is evident that the main four warehouse zones collectively account for 98.5% of the total picked lines in 2024. The remaining zones, grouped under the category “Other,” contribute only marginally and all of them fall outside the scope of this study.

However, the number of picked lines generated in a given warehouse zone may be influenced and potentially biased by the number of items stored in that zone. In other words, a warehouse zone might appear to include high-rotation items simply because it contains a larger number of distinct items, which increases the probability of generating picking orders. To address this potential distortion, an additional analysis was carried out in order to normalize the number of picked order lines with respect to the number of items stored in

each warehouse zone. This makes it possible to evaluate how much each item, on average, contributes to the generation of picking lines.
For this purpose, a **Picking Intensity Ratio (PIR)** was introduced, defined as follows:

$$PIR = \frac{\textbf{\textit{Total Picked Lines in Zone}}}{\textbf{\textit{Number of items stored in Zone}}}$$

This indicator expresses the average number of picked lines generated per stored item within each warehouse zone. A high PIR value identifies zones characterized by high-rotation items, since it indicates that, for an equal number of stored items, more picking orders are generated. Consequently, zones with higher PIR values can be associated with higher rotation classes in the ABC classification.
Although no equivalent metric has been explicitly defined in the literature, the **PIR** concept is aligned with the ratio-based performance indicators proposed by **Karim et al. (2021)**, who suggest measuring warehouse productivity through relationships between picking outputs and input resources, such as labour, equipment, or inventory levels. Their approach supports the validity of adopting ratio-based indicators to evaluate the operational performance of warehouse zones.

The table 2 below reports, for each warehouse zone previously analyzed in the Pareto chart, the total number of picked lines in 2024, the number of stored items (identified by their PN , Part Number, code), and the resulting PIR value.

WAREHOUSE ZONE	Sum of Picked Lines	Count of Items stored (PN)	PIR
BLUMAG	596320	2849	209
DEMAG	2721311	27432	99
P&P	909145	31255	29
SCR	533589	30083	18

Table 2: Picking Intensity Ratio (PIR) by warehouse zone

As a result, by combining the outcomes of the Pareto analysis with the Picking Intensity Ratio (PIR) for each warehouse zone, the main areas of the Turin warehouse can be classified as follows:

- BLUMAG → Rotation Class A
- DEMAG → Rotation Class A
- P&P → Rotation Class B
- SCR → Rotation Class C

Weight and Volume analysis

The ABC analysis used to determine the most suitable storage area is further supported by an additional evaluation based on the weight and volume of the items to be stored.

As with the ABC classification, it was not feasible to conduct this analysis at the individual item level, due to the large number of products managed within the Kuehne+Nagel warehouse in Turin. Therefore, the analysis was carried out at the warehouse zone level, by aggregating the data of individual items into average values for both volume and weight per zone.

This aggregation enabled the identification of the average physical characteristics of the units stored in each of the main warehouse zones. Table 3 below presents the detailed results of this analysis:

Warehouse Zone	Average of WEIGHT [kg]	Average of VOLUME [m3]
BLUMAG	1,72	0,83
DEMAG	0,21	0,23
P&P	1,64	2,50
SCR	15,81	8,00

Table 3: Average Weight and Volume of items stored in Warehouse Zones

The results presented in the table demonstrate that the average volume and weight of the items stored in the DEMAG and BLUMAG zones are significantly lower than those of the items stored in the other warehouse zones, such as P&P, and SCR.

The analysis conducted above, as previously described, represent a key discriminant in determining the most appropriate warehouse zone for incoming goods once they arrive in the Inbound area and are prepared for storage.

Furthermore, the results of these two analyses will also be used for the purposes of this project in a different way, serving as a discriminant for the separation of two distinct flows within the Shipping Flow. This separation will be further explained and detailed in the following chapter, specifically in paragraph 6.2.

4.2.5. Functional and Structural Characterization of Warehouse Zones

This section introduces the structural and functional characteristics of the main zones within the Kuehne+Nagel warehouse located at the Iveco site in Turin. The description focuses on the layout, operational logic, and material handling processes specific to each zone. Figure 21 provides an overview of the warehouse areas, indicating the square meters allocated to each section.

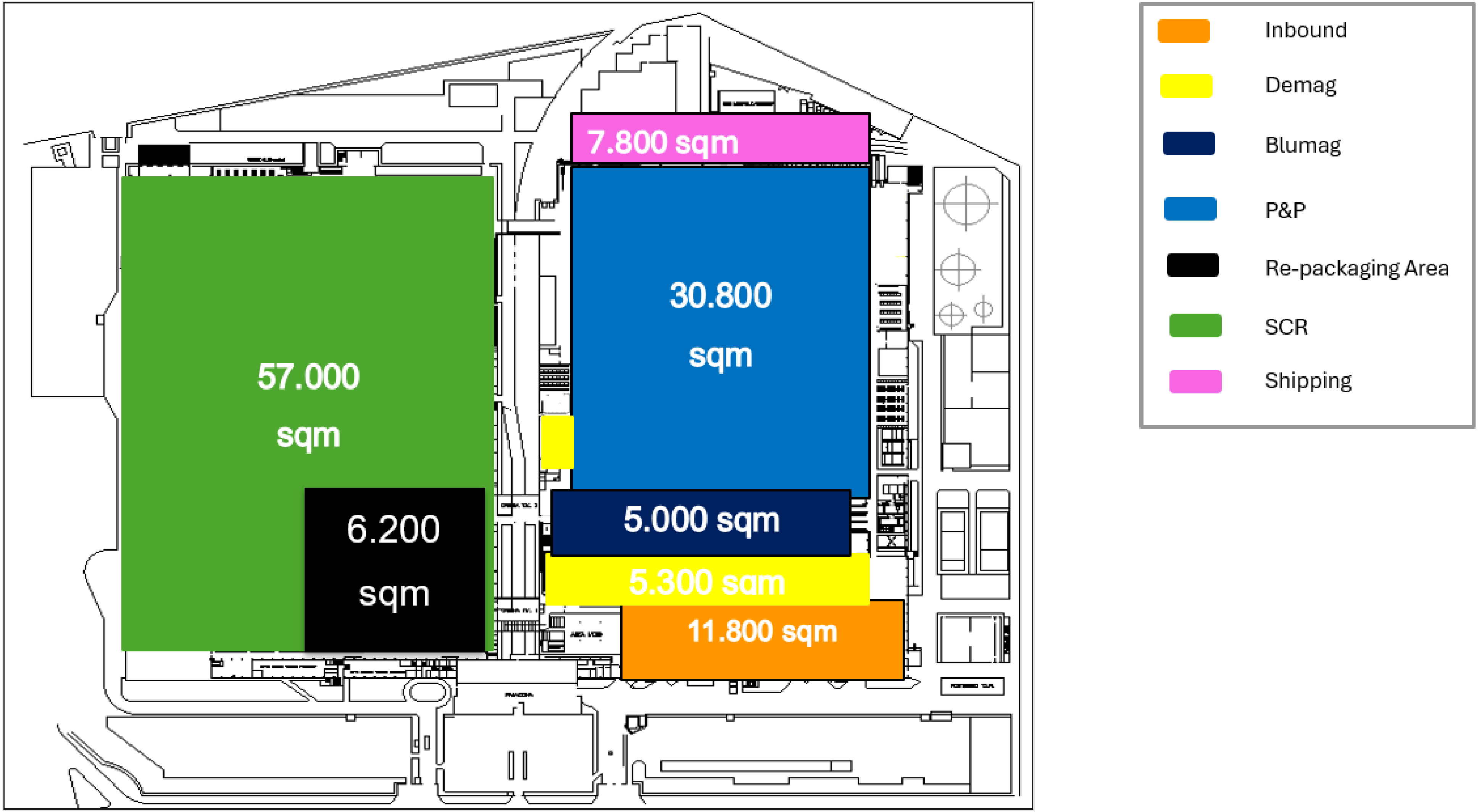

Figure 21: Turin Warehouse Layout with detailed surface area allocation

4.2.5.1. DEMAG

The DEMAG area, located within the CDR site in Turin, is an automated warehouse occupying approximately 5,300 m².

Despite its relatively limited footprint compared to other areas of the site, it plays a key role in operational efficiency, managing around 50% of the total daily outbound order lines (a detailed analysis of this performance is reported in paragraph 4.2.4.).

From a structural point of view, DEMAG is designed to store small and fast-moving spare parts using standardized Odette bins, each measuring 600x400x300 mm (Figure 22). The total number of bins the system can accommodate is approximately 108.884**,** representing the maximum theoretical receptivity of the warehouse.

Functionally, DEMAG integrates an automated storage and retrieval system, an overhead conveyor belt, and dedicated areas for picking, refilling, inventory control, and packing**.**

Figure 22: Odette container DEMAG

Nine workstations are used for picking activities and five bays dedicated for packing activities. The packaging operators are responsible for consolidating customer orders and preparing items for final shipment. Outbound parcels are processed using different packaging methods, depending on the size and handling requirements of the items:

Once packaged, all items are transferred to a buffer area using front-fork forklifts. This buffer serves as an intermediate storage zone before the goods are moved to the shipping area for final dispatch to the end customer.

The internal transport and handling process toward the shipping department, which is the focus of this case study, will be described in detail in the following chapter.

4.2.5.2. BLUMAG

The BLUMAG warehouse is a newly implemented automated storage system (November 2023) located adjacent to the DEMAG area within the Kuehne+Nagel logistics hub in Turin. It occupies a total surface of approximately 5,000 m² and is equipped with high-density racking systems managed by five dual-column stacker cranes operating on 152 aisles and 10 vertical levels, with double-deep storage capability. The total storage capacity amounts to around 30,000 locations.
(Sgro, M., 2023, Analysis of the new automated warehouse installed at the IVECO spare parts facility (Turin), managed by logistics operator KUEHNE+ NAGEL (PhD Thesis). Politecnico di Torino)
Items are stored in standardized blue Odette containers, each measuring 600×800×520 mm (Figure 23), which can be subdivided into up to four compartments depending on the size and quantity of the stored items. Each container can hold up to 100 kg of material.

Figure 23 Odette container BLUMAG

The process is supported by Put-To-Light technology and weight control systems, to guarantee accuracy for the creation of shipping units.

Once the items are picked, they are transferred via the final conveyor to the packing stations, where an operator closes the shipping box and applies the shipping label. A dedicated bay is reserved for small boxes, typically corresponding to single-line orders;

in this area, the packed boxes are grouped into larger carton boxes to facilitate internal handling and transportation.

When the boxes are ready, a forklift operator collects and places them in a temporary buffer area. From there, the boxes are loaded onto the *Tugger Train* and transferred to the shipping department for final dispatch.

4.2.5.3. SCR

The SCR warehouse area covers approximately 57,000 m² and is primarily dedicated to the storage of large, heavy, and low-turnover items.
Structurally, around 75% of the area utilizes block stacking (floor stacking), while the remaining 25% is equipped with traditional racking systems. Due to the wide variety of item dimensions and handling requirements, the racking configurations vary significantly across sub-zones, with differences in the number of uprights and shelf levels depending on the specific storage needs of each section. (Sgro, M., 2023, Analysis of the new automated warehouse installed at the IVECO spare parts facility (Turin), managed by logistics operator KUEHNE+ NAGEL (PhD Thesis). Politecnico di Torino)
Despite its large footprint, the SCR area processes only about 11% of the total daily outbound order lines.

For the purposes of this case study, it is essential to distinguish a specific sub-area within SCR, referred to as 1R–1S, from the rest of the zones. This separation is necessary because the outbound material flow from 1R–1S to the shipping department follows a distinct operational logic and must be analyzed independently. Items stored in zone R are directly picked and, due to their high bulk and incompatibility with further palletization or wrapping, are already packed for final shipment. These items undergo only a labeling step—where the shipping tag is applied—before being placed in a buffer and subsequently transported to the shipping department.
Conversely, items stored in zone S are picked and then subjected to tertiary packaging operations within dedicated packing stations. Once packed, they are also placed in a buffer and transported to the shipping department. The proximity of zones R and S justifies their consolidation into a single outbound/shipping flow, despite the slight differences in their handling processes.
In contrast, the remaining areas of the SCR warehouse follow a more conventional outbound process. Picked items are transferred to a centralized packing area, which consists of ten individual stations where the goods are prepared for shipment.

All outbound parcels, regardless of packaging type, are placed in a buffer using front-fork forklifts and then transported to the shipping department, using the *Tugger Train*, for final dispatch to the customer.

4.2.5.4. P&P

The Pick & Pack (P&P) warehouse, located within the CDR area of the Kuehne+Nagel logistics hub in Turin, occupies a total surface of approximately 30.800 m². It is generally divided into storage sub-zones and the packaging zone, which is the area where items previously picked are packed and prepared for final shipment.
Structurally, the storage area is predominantly equipped with traditional racking systems, which account for approximately 94% of the total area, while the remaining 6% is allocated to block stacking. The difference between the sub-zones is based on specific item categories and storage configurations.

Sub-zones E1, E2, E3, and E6

These sub-zones are equipped with traditional shelving designed to accommodate standard pallets (1000 × 800 × 800 mm) and are used for storing items of medium weight and volume. The picking process in these areas is carried out using order-picking trucks.

Sub-zone E8

It is equipped with traditional shelving which accommodates larger pallets (1700×1100×1100 mm), where items with larger volume but lightweight, such as mirrors, window regulators, and fenders, are stored. The picking process is performed using reach trucks to handle the retrieval of bulkier items stored on higher racking levels.

Sub-zone KT

Structurally, this sub-zone is organized using block stacking and is characterized by high-density storage of homogeneous items. This area is dedicated to the storage and handling of filter components. Functionally, it supports high throughput picking operations, typically involving full pallets or large batches. Packaging activities for the items retrieved from this sub-zone are carried out directly within the storage area by the picking operators.

For the objectives of this case study, it is essential to identify and describe these sub-zones separately, as each of them is included in the Storage Flow analysis, as they form part of the storage process of incoming materials. Additional details regarding the involvement of these specific zones within the material handling flow analyzed in this case study will be provided in Section 7.2.

Conversely, all the sub-zones of the P&P warehouse area are considered out of scope for the Shipping Flow analysis, since the proximity of the packing areas to the Shipping Department (demonstrated by the layout reported below in Figure 24) allows for the direct transfer of packed items without requiring intermediate transport via Tugger Train.

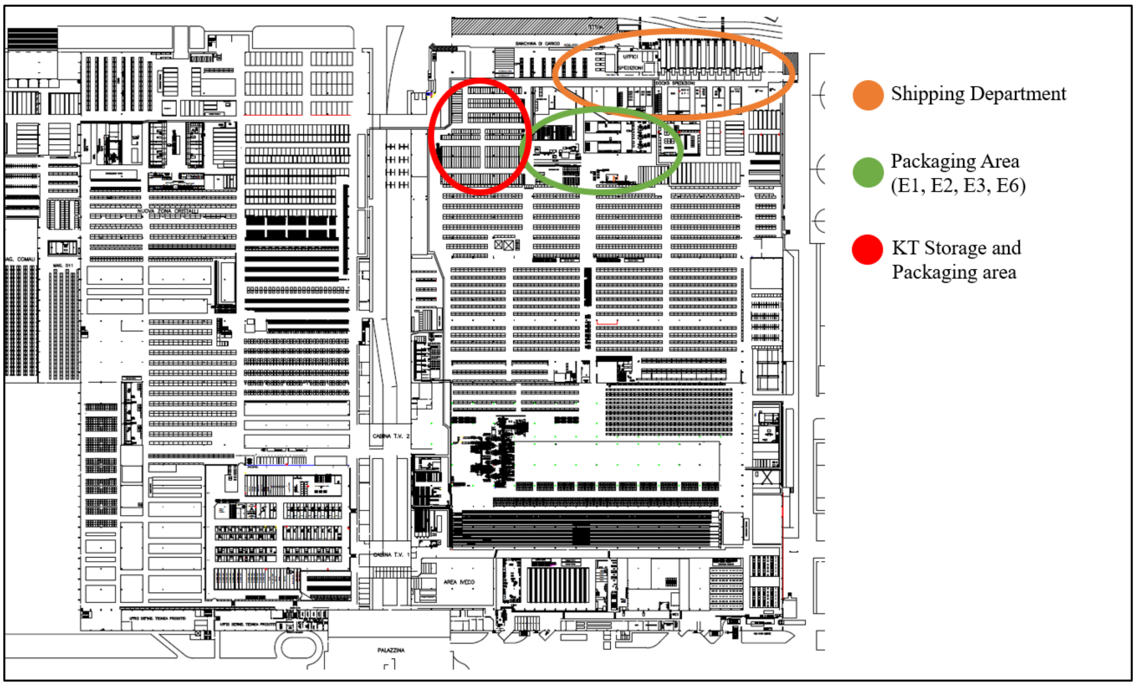

Figure 24: Warehouse Layout – P&P sub-zones and their proximity to the Shipping Department

To summarize all the information related to the different storage zone inside the Kuehne-Nagel Turin Warehouse, Table 4 below provides a schematic representation of their main characteristics, including the surface, the storage capacity, the type of load unit, the storage system, and the handling system and equipment employed.

Warehouse Zone	Surface [m²]	Storage Capacity	Load Unit	Storage System	Handling System
DEMAG	5.300	~ 108.000 bins	Yellow Odette bins (600×400×300 mm)	Miniload	Single-depth stacker cranes, double-depth stacker cranes, and automatic conveyors
BLUMAG	5.000	~30.000 bins	Blue Odette bins (600×800×520 mm)	Miniload	Dual-column stacker cranes and automated conveyors
SCR	57.000	not standardized, variable	Large/variable items stored on pallets or bulky units	75% block stacking, 25% conventional racking	Front-fork forklifts and reach trucks
1R-1S (SCR sub-zone)	/		Bulky units	Block stacking storage system	Front-fork forklifts and reach trucks
P&P	39.000	21.000 storage locations: 16.000 picking points and 5.000 replenishment locations	Standard pallets (1000×800×800 mm) Large pallets 1700×1100×1100 mm	94% conventional racking 6% block stacking	Order-picking trucks, front-fork forklift, reach trucks
KT (P&P sub-zone)	/		Bulky units (pallettized)	High-density block stacking	Front-fork forklift

Table 4: Warehouse zones overview

This concludes the overview of the warehouse layout, operational flows, and storage areas, providing a clear understanding of the context of the Kuehne-Nagle Turin warehouse, particularly with regard to the areas and flows involved in the improvement project that will be analyzed in this study, in the following chapters.

5. Improvement Project of the Material Handling Process

5.1. Methodology Approach adopted for the Project

For the study and implementation of the improvement project presented in this thesis, a methodological approach based on the Lean Six Sigma framework was adopted. In particular, the DMAIC cycle (Define, Measure, Analyze, Improve, and Control) was applied as the guiding structure for the project. This methodology, often described as an approach for problem solving, integrates the principles of Lean Production—focused on process optimization through the elimination of inefficiencies and waste, while maximizing value for the customer—with the Six Sigma approach, which emphasizes the systematic use of data analysis to understand processes and variability (de Mast & Lokkerbol, 2012). The combination of these two perspectives enables a structured and data-driven development of improvement initiatives, ensuring that solutions are not only effective but also sustainable over time (de Mast & Lokkerbol, 2012).

In addition to providing a comprehensive view of process performance, the DMAIC methodology facilitates the identification of root causes of inefficiencies (root causes) and the design of targeted countermeasures. The five phases of the cycle can be summarized as follows (de Mast & Lokkerbol, 2012):

- **Define**: this phase focuses on the definition of the project scope and objectives, as well as on the identification of critical aspects of the process through tools such as process mapping.
- **Measure**: in this phase, process performance in the AS-IS state is quantified through the collection of relevant data and the measurement of Key Performance Indicators (KPIs).
- **Analyze**: the collected data are analyzed to identify the root causes of inefficiencies and to establish cause–effect relationships within the process.
- **Improve**: in this phase, improvement solutions are designed and implemented with the objective of addressing the identified root causes and enhancing process performance.
- **Control**: the final phase involves monitoring the TO-BE process through data collection and KPI measurement, in order to assess the effectiveness of the implemented solutions and ensure their long-term sustainability.

Although the DMAIC cycle is here presented in its theoretical form, in practice its tools and concepts were tailored and adapted to the specific case study of the Kuehne-Nagel Turin warehouse, ensuring their applicability and effectiveness in this operational context.

6. Define Phase

The first phase of the project focuses on a detailed analysis of the main components of the case study, including the project objectives, the operational flows involved, the identified weaknesses, and the possible areas for improvement.

6.1. Introduction to the Project

The project under analysis focuses on the material handling process between departments within the Kuehne+Nagel warehouse located at the Iveco site in Turin. As described in Sections 4.2.2 and 4.2.3, the main macro-flows managed in the warehouse are the Storage Flow, the Outflow, and the Shipping Flow. Among these, the flows relevant to the development of the project presented in this thesis are the *Storage Flow* and the *Shipping Flow*.

The handling process is structured in several steps: in each originating department, a forklift operator loads the material from temporary buffers onto wagons, which are coupled together in blocks of three. Once the loading is completed, a dedicated operator is called to initiate the transport.

The material movement is carried out using a motorized vehicle, like a small locomotive, which connects to the group of loaded wagons. The combination of the three wagons and the motor unit is referred to as a "*Tugger Train*", a term that will be used throughout the following sections to describe the handling process.

The Tugger Train operator drives the unit to the designated destination area, where a forklift operator unloads the material from the wagons, making it available for the subsequent processing stage.

Figure 25 provides a visual representation of a Tugger Train, composed of the motor vehicle and the three connected wagons.

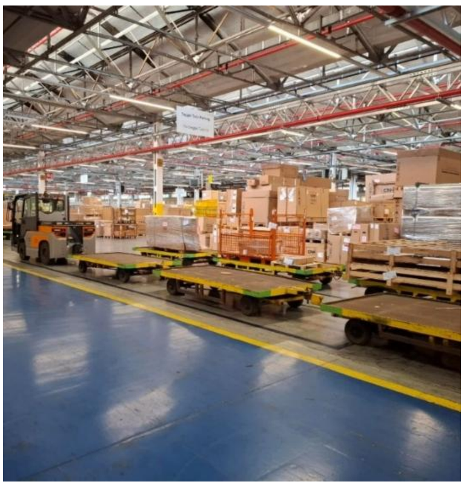

Figure 25 Tugger Train: Motor Vehicle connected to 3 Wagons

6.2. Definition of the Operational Flows

In order to optimize the material handling process more effectively, it was necessary to consider the operational flows separately. This subdivision proved essential for analyzing and identifying the different flows in greater detail, allowing for targeted improvements based on the specific requirements of each flow.
Hence, the two main macro-flows under project analysis are the **storage flow** and the **shipping flow**.

<u>Storage Flow:</u>

As described in paragraph 4.2.2, the *Storage Flow* concerns the material arriving from the Inbound department, where goods coming from other warehouses undergo an initial computerized processing phase for data acquisition. During this acquisition phase, the operator also performs a preliminary sorting of the material based on the ABC classification and the weight and volume characteristics of the items (as described in paragraph 4.2.4), to determine the appropriate storage zone within the warehouse.

Subsequently, a forklift operator uses a front forklift to accumulate the goods within buffer areas, from which the material will later be picked up, loaded onto wagons, and transported to different warehouse zones for storage.

In some cases, depending on the specific type of material, the flow known as *Ricevimento Merci* involves an intermediate physical step consisting of repackaging in a dedicated *"Re-packaging Area",* before storage.

The repackaged material is then transported from the repackaging area to the respective storage zones within the warehouse using a *Tugger Train*.

Figure 26 shows a flowchart describing the storage flow.

<u>Shipping Flow:</u>

On the other hand, the *Shipping Flow* involves the material picked and then packed in the packing areas of the various warehouse zones. After packing, a forklift operator uses a front or reach forklift to place the goods in dedicated buffer areas. The material is then loaded onto wagons and transported to the Shipping department, using the *Tugger Train*, where the material is subsequently sorted and dispatched to the final customer.

Figure 27 shows a flowchart describing the shipping flow.

As described previously, in paragraph 4.2.3, the transported material can have different types of packaging depending on the nature of the items, the customer's order, and the warehouse of origin, like single small packages placed inside carton boxes, pallets, or large and heavy single skids.

Based on the type of transported material and specific indicators, which are item weight, volume, and ABC classification, analyzed in the section 4.2.4, the shipping flow can be further subdivided into two distinct operational sub-flows:

- **Small, lightweight, and high-turnover materials**: These items are mainly handled by the automated warehouses (DEMAG and BLUMAG) and sent to the Shipping department. The handling of this flow is characterized by high frequency, fast picking operations, and limited weight and volume of the packed materials.
- **All other materials**: This category includes goods coming from the remaining warehouse zones. Their handling is tipically marked by lower picking frequency and/or larger, heavier packaging units.

During the initial KPI measure phase in the AS-IS scenario, both these flows are examined jointly to provide a comprehensive overview of the current material handling process. In the subsequent Improve phase, when optimization solutions will be defined and studied, the two flows will be considered separately to enable the identification of tailored improvement strategies for each material category.

Both macro-flows, the storage and the shipping flow, have been described in a summarized manner, with the objective of providing a general overview of the material handling process. This preliminary description aimed to illustrate the overall structure of the flows, including the preceding phases and the equipment employed throughout the operations.

In the following section, the handling process will be mapped in a more precise and detailed way, with the goal of identifying Value-Added activities (VA), Non-Value-Added activities (NVA), and Non-Value-Added but Necessary activities (NVAN). This analysis will allow for the identification of inefficiencies and wastes within the process and, consequently, the recognition of potential areas for improvement.

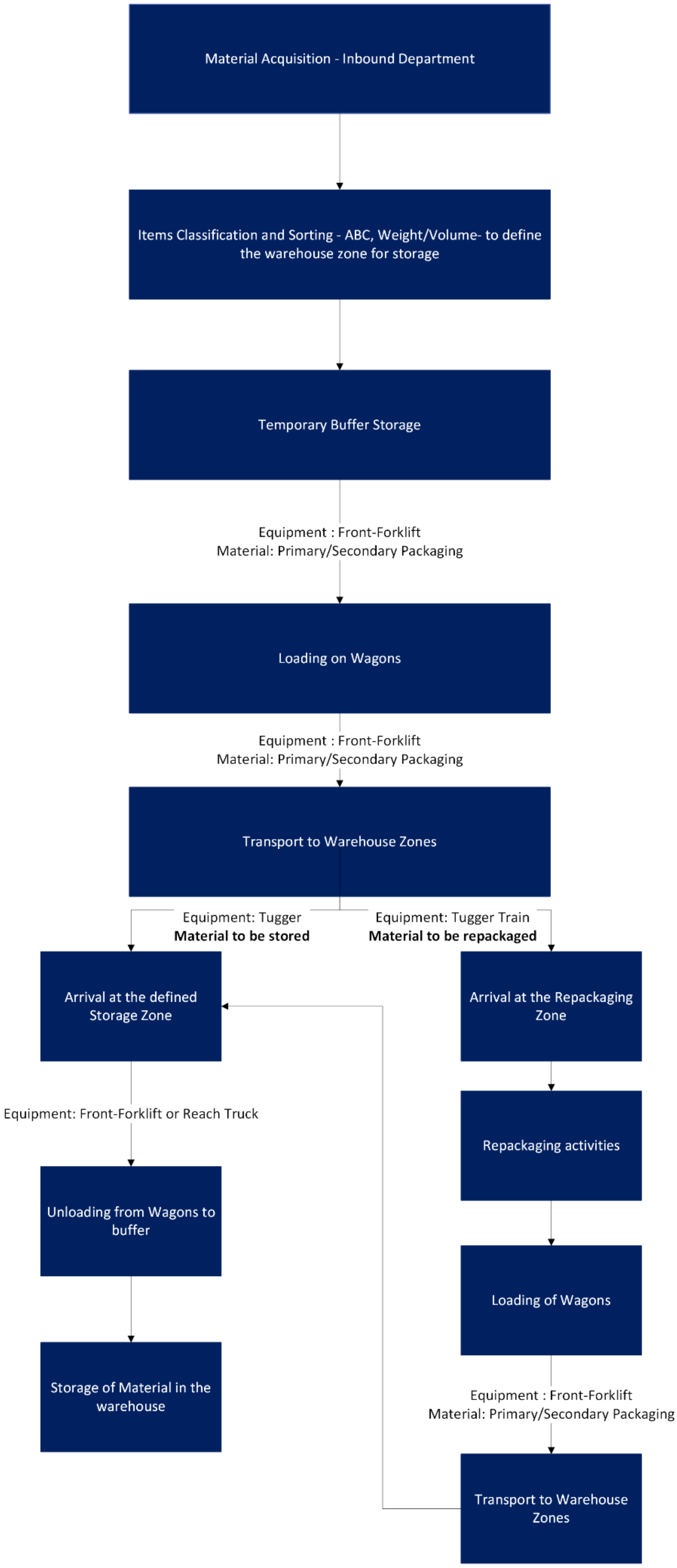

Figure 26: Flow Chart Storage Flow

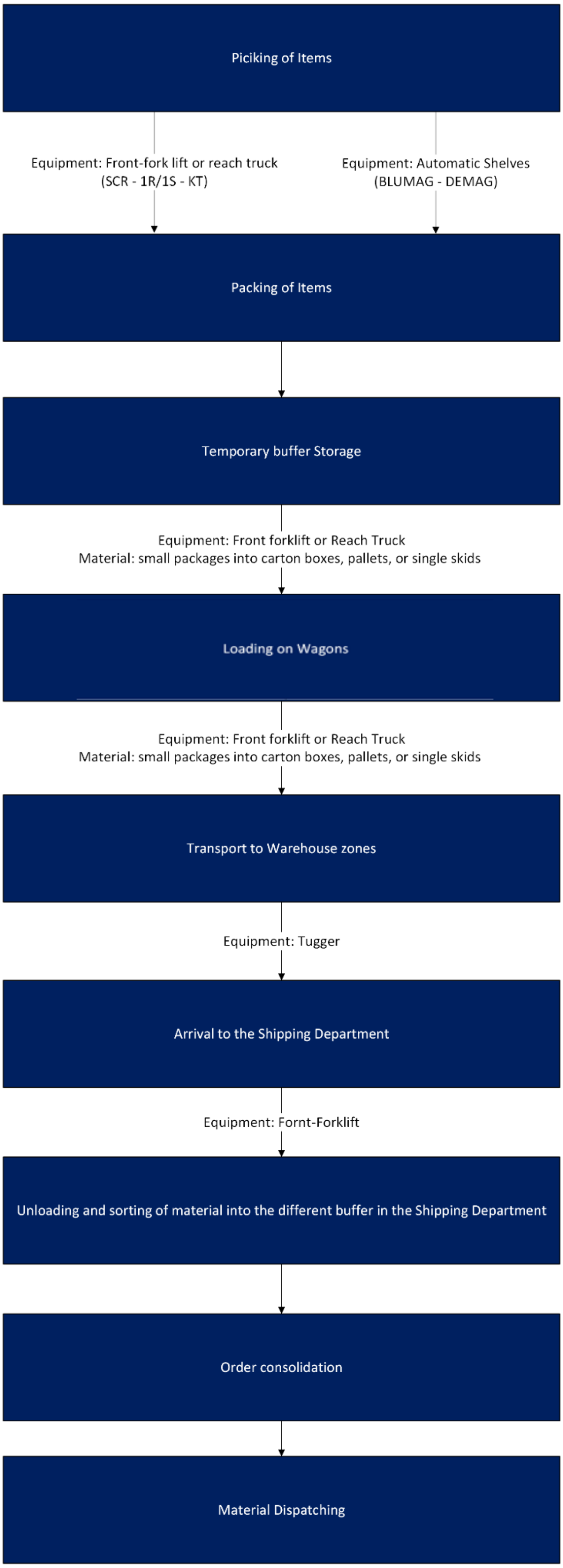

Figure 27: Flow Chart Shipping Flow

6.3. Process Mapping and identification of Wastes

This section provides a detailed process mapping of the material handling flow carried out by Tugger Train drivers. In general, the handling cycle begins at the origin point of a specific route, where the forklift operator of the area first verifies the availability of an empty wagon at the parking station in order to start the material loading operations. If no empty wagon is available, the operator must wait until a Tugger Train driver completes a previous handling mission and returns an empty wagon to the station. In such cases, the Tugger Train driver is also required to wait for the direct loading of material onto the wagon, since the operation cannot be performed in advance due to the unavailability of an empty wagon at the origin station.

The ***Origin points*** correspond to the stations within the internal handling process where material is initially loaded for subsequent processing. More specifically, these include:

- All the station within the *Outflow Areas* (warehouse zones) of the Shipping Flow, where material is prepared to be transferred to the Shipping Department for final dispatch to customers;
- The station within the *Repackaging Area*, where repacked material must be moved to the designated warehouse zones for storage;
- The station within the *Inbound Department*, where material arriving from external warehouses or third-party suppliers is loaded onto wagons to be transported to the appropriate warehouse zones or to the repackaging area.

Once the material is loaded, the Tugger Train driver hooks the wagon, and transports the loaded material to its designated destination point. ***Destination points*** are defined as the stations where material arrives and must be unloaded to undergo the next processing step. These include:

- All the stations within the *Warehouse zones*, where material from the Inflow Department or the Repackaging Area must be stored;
- The station of the *Repackaging Area*, which receives material from the Inflow Department requiring repackaging activities (the "Ricevimento Merci" flow described in Section 4.2.3.1);
- The station within the *Shipping Department*, where material picked and packed in the outflow zones is transferred for final dispatch to customers.

Upon arrival at the destination point, the Tugger Train driver verifies the availability of a parking slot. If it is not available, the driver must wait in queue. Once the slot becomes available, the wagon is positioned, and the driver proceeds to unhook the full wagon. If an empty wagon is already available, it is immediately hooked in order to return it to the origin point and resume the next material movement. If no empty wagon is available, the driver must wait until the unloading is completed before returning the empty wagon to the origin point and restarting the handling cycle.

The detailed representation of each step of the material handling process, performed by the Tugger Train in the Kuehne-Nagle Turin Warehouse, is drawn in the process mapping reported in Figure 28 below.
The flow chart highlights potential inefficiencies by distinguishing value-added (VA), non-value-added (NVA), and non-value-added but necessary (NVAN) activities, color-coded respectively in green, red, and yellow.

As observed in the process map, the main sources of waste identified are related to waiting times caused by the unavailability of parking space at the arrival station or the absence of an empty wagon for hook/unhook operations (this activity are highlighted as NVA, in red). These situations force the *Tugger Train driver* to wait for the forklift operator to unload/load the material, creating an additional waste due to the waiting for the direct material unloading/loading.

In addition to these inefficiencies, the initial project analysis revealed further wastes related to the following critical issues:

- **Lack of traceability**: The material loaded, and the Tugger Trains themselves are not tracked, making it impossible to obtain real-time updates on material status and delivery times within the warehouse.
- **Inflexibility**: The process is inherently static, as the Tugger Train drivers follow fixed routes with predetermined routes that cannot be adjusted, limiting operational flexibility.
- **Lack of precision in internal deliveries**: Materials frequently arrive late to the Shipping department, requiring the intervention of forklift operators to search the missing packages around the warehouse zones.
- **Excessive slowness of the process**: The material handling process is particularly slow due to long travel distances and a non-continuous flow. The Tugger Train must be fully loaded before it can be moved, which increases waiting times.

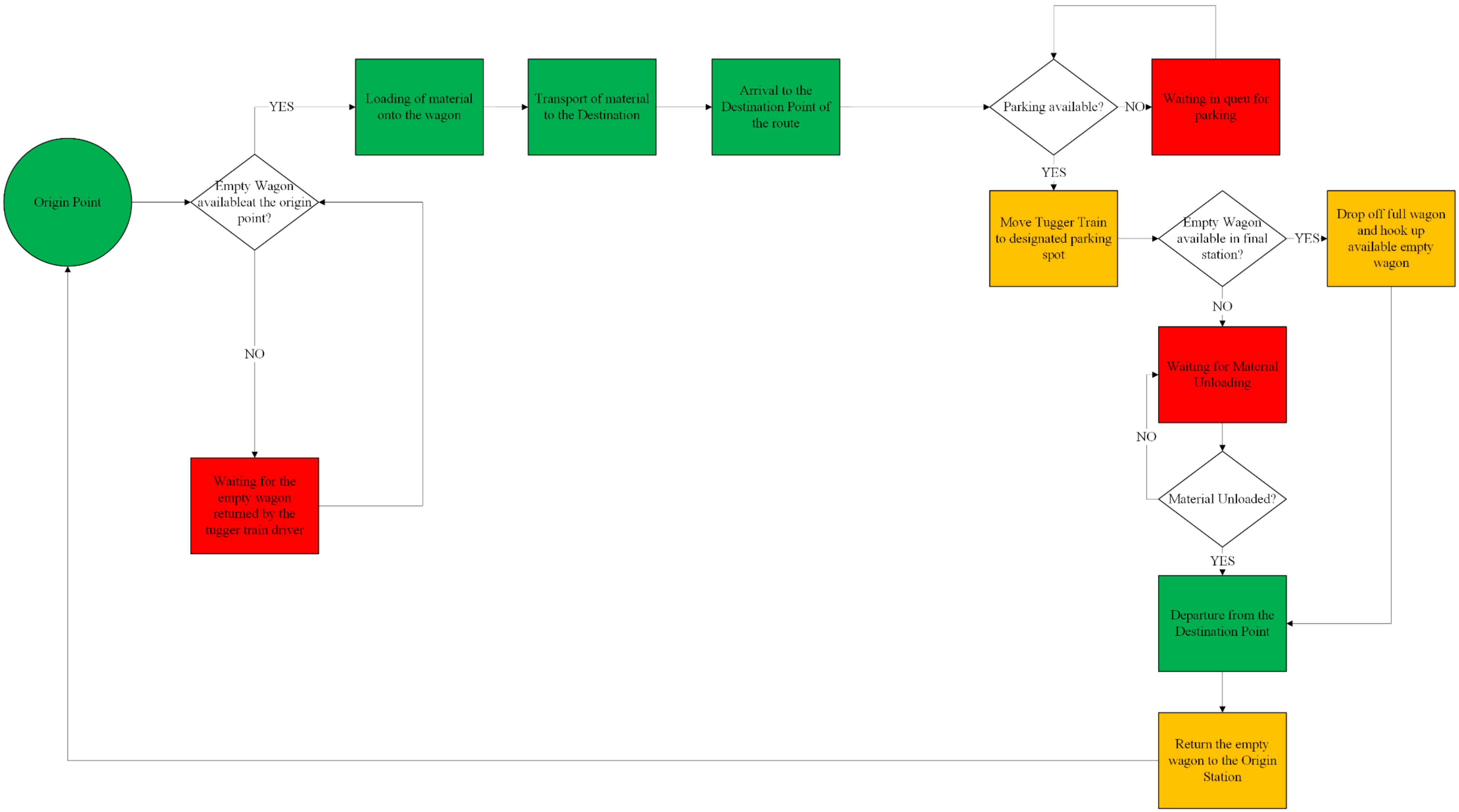

Figure 28: Process Mapping Material Handling Flow

6.4. Project Objectives

Considering the identified critical issues, the project objectives have been defined.

The goal is to optimize the overall efficiency of the material handling process, thereby contributing to the improvement of the warehouse's operational performance. Specifically, the project aims to reduce or eliminate the identified wastes—i.e., non-value-added activities—and to optimize value-added activities.

Five specific operational objectives have been established:

1. **Accelerate the material handling process** by optimizing the routes traveled within the warehouse,
2. **Reduce/Eliminate the waiting time** by introducing specific solution to avoid the waiting for the loading/unloading of materials in the origin or destination poitns,
3. **Increase operational flexibility** through the introduction of synergy between departments and the creation of a shared Tugger Train fleet,
4. **Implement a traceability system** to monitor the load on each vehicle and track material positioning throughout the handling phases,
5. **Reduce internal delivery delays** to the shipping department by eliminating manual searches for missing packages and ensuring greater punctuality in shipment consolidation.

This initial process analysis provides an overview of the most critical inefficiencies identified during the early stages of the project. In the following sections, a more detailed assessment will be carried out by quantifying the impact of the most relevant wastes through specific KPI measurements. Efforts will be focused on measuring the AS-IS performance of the current process, in order to assess the extent of potential improvements.

Based on this analysis, possible root causes and related improvement solutions will be identified.

This approach will make it possible to address criticalities effectively, with the objective of achieving a more efficient and less wasteful process, increasing the overall value delivered to the customer.

7. Measure Phase

The Measure phase is used to assess the current performance of the material handling process. The goal is to establish baseline metrics, measure the AS-IS performance, and quantify improvement opportunities through data collection and analysis.

7.1. Overview on Key Metrics analyzed

In general, the KPIs used in this case study to analyze the material handling process cover key aspects related to **operational efficiency** and **route/flow optimization**.

As previously discussed in Section 2.4, some KPIs defined in the literature were adopted and subsequently adapted to the real context of the project under analysis. In this section, in addition to providing a specific definition of the KPIs applied in the study, a comparison with those described in the literature is carried out. This approach demonstrates how the main KPIs, traditionally considered essential for assessing warehouse processes performance in the literature, can be applied in practice within this project, even if with some necessary modifications and adjustments.

Operational Efficiency KPIs:

- **Process Time (PT):** total time spent to complete the entire material handling operation, including loading, transport, unloading and any associated stops or activities. This indicator is calculated as the sum of the following KPI and variables, which will be described in detail in section 7.2.3: waiting time (T_w), loading/unloading time ($T_{u/l}$) and cycle time (CT).
  This KPI can be related to the *"Handling Cycle Time"*, described in literature as "the total time required to complete a full handling operation from start to finish" (Section 2.4.1). Nevertheless, its definition has been revised and adapted to the specific requirements of the process under analysis.

- **Cycle Time (CT)**: actual time required to move from point A to point B in the warehouse, as measured during the observation period. It includes variability caused by operational conditions, such as interruptions along the route or fluctuations in vehicle speed. Conceptually, it is consistent with the KPI *Cycle Time* defined in the literature as "the total time required to complete a loading/unloading operation" (Favetto et al.), but adapted here to represent the real travel time in the internal material handling process.

- **Tugger Train Efficiency (E):** ratio of Cycle Time (CT), divided by the total Process Time (PT). In the literature, this concept is generally framed under the KPI of *Resource*

Utilization, described as "the percentage of time in which resources (humans or vehicles) perform operations" (Section 2.4.1). Although expressed with a different terminology, Tugger Train Efficiency can be considered as the specific application of Resource Utilization to Tugger Trains. For the purposes of this project, however, the KPI will be exclusively referred to as Tugger Train Efficiency. More specifically, it indicates the percentage of operative time spent in pure travel activities for material handling, as opposed to waiting, loading, and unloading times. The resulting measure reflects the operational efficiency and utilization of the transport equipment (Tugger Trains).

- **Delivery Inaccuracy Rate (DIR):** this KPI is specific to the analysis of the Shipping flow and was defined for the specific context of the project, in collaboration with the company. It measures the percentage of units delivered late out of the total number of units delivered daily to the Shipping department from the Outflow areas. This index serves as an indicator of the timeliness of the internal shipping process within the warehouse.

Path optimization KPIs:

- **Distance traveled (D):** in the literature, this KPI is defined as "the total distance traveled by the picker or the vehicle to move between the input/output point of the warehouse" (Section 2.4.1). In the context of this case study, the definition was adapted to represent the distance covered from the starting to the ending point of the routes involved in the material handling process performed by Tugger Train drivers. This KPI measures the internal movement paths by evaluating the distance traveled per each flow (Shipping and Storage), in terms of meters carried out daily.

- **Theoretical Cycle Time (CTth):** represents the estimated travel time required to move from point A to point B under ideal operating conditions, without considering interruptions, delays, or variability in speed. This KPI conceptually corresponds to *Travel Time* as defined in the literature by Favetto et al., where it is defined as the total time needed by a vehicle to move between warehouse points. In this study, the theoretical Cycle Time is obtained by dividing the distance traveled (D) by the nominal travel speed of the Tugger Train.

The table 5 below summarizes the information regarding the KPIs analyzed in this study, providing their definition, the calculation formula, and the corresponding bibliographic reference when available.

In the following sections, the KPIs related to each specific material handling flow, Storage and Shipping Flow, will be analyzed and calculated in detail, explaining the formula and the calculation method used.
This approach enables a more targeted and in-depth analysis, allowing for the identification of the main criticalities and inefficiencies within the material handling process in Kuehne-Nagel Turin warehouse.

Cluster	KPI	Definition	Formula	Reference
Operational Efficiency	Process Time (PT)	Total time spent to complete the entire material handling operation from start to finish	$PT = T_w + T_{u/l} + CT$	Adapted from Vuong (2020)
	Cycle Time (CT)	Actual time required by the vehicle to complete a movement between the starting and ending point, considering operational conditions and delays	CT = Daily Frequency (Route x,y) x Average Cycle Time (Route x,y) (calculated from data collected during the observation period)	Adapted from Faveto et al. (2023)
	Tugger Train Efficiency (E)	The percentage of time in which resources - tugger train in this specific case - perform effective operations	E = CT / PT	Adapted from Faveto et al. (2023)
	Delivery Inaccuracy Rate (DIR)	Percentage of units delivered late out of the total delivered daily to the Shipping department.	DIR = (Late deliveries / Total deliveries) × 100	Defined internally in collaboration with the company
Path Optimization	Distance Traveled (D)	The total distance traveled by the vehicle to move between the starting and ending point of the route	D = Σ (distance traveled per route)	Adapted from Faveto et al. (2023)
	Theoretical Cycle Time (CTth)	Estimated travel time required to move between the starting and ending point under ideal conditions, calculated as Distance/Speed.	CTth = Distance (Route x,y) / Average Speed	Adapted from Favetto et al. (2023)

Table 5: KPIs analyzed in the study

7.2. Storage Flow

The storage flow, as described in Section 6.2., refers to the handling of inbound material received in the *Inbound* area of the warehouse. From this point, products are directed either to the various storage areas or to the *Repackaging Area*.
In the latter case, materials are repackaged according to the specific requirements of the customer and subsequently transferred to the designated warehouse areas for storage.
In addition to this, a *Cross-docking flow* is also present, in which materials received in the Inbound area are directly transferred to the Shipping Department, bypassing storage, and immediately prepared for final delivery to the customer.

Based on the operational requirements of the storage flow, material movements follow the routes listed below:

- **INBOUND (1) – BLUMAG-PUTAWAY (2)**
- **INBOUND (1) – P&P 10 (3)**
- **INBOUND (1) – P&P 80 (4)**
- **INBOUND (1) – KT (5)**
- **INBOUND (1) – SCR-PUTAWAY (6)**
- **INBOUND (1) – REPACKAGING AREA (7)**
- **INBOUND (1) – SHIPPING (8)**
- **REPACKAGING AREA (7) – BLUMAG-PUTAWAY (2)**
- **REPACKAGING AREA (7) – P&P 10 (3)**
- **REPACKAGING AREA (7) – P&P 80 (4)**
- **REPACKAGING AREA (7) – SCR-PUTAWAY (6)**

Each route follows a fixed predetermined path, set by the internal traffic flow of the warehouse (highlighted by the blue lines in figure 29 below).
To better understand the connections and the location of the stations within the warehouse, further clarification of some stations listed above is necessary. The **KT station** is used for unloading material destined for the KT sub-zone. The **P&P 10 station** is dedicated to the unloading of material stored in sub-zones E1, E2, E3, and E6, while the **P&P 80 station** is used for material stored in sub-zone E8 of the P&P warehouse zone (previously described in Section 4.2.5.4). Similarly, the **SCR-PUTAWAY station** manages the unloading of material directed to

storage in the SCR warehouse zone, and the **BLUMAG-PUTAWAY station** handles material to be stored in the BLUMAG warehouse zone.

It is also important to underline that within the storage flow, the Inbound department functions exclusively as an origin point, while the Repackaging Area serves as both an origin and a destination point, since it receives material to be repackaged and subsequently dispatches it to storage zones. Conversely, the warehouse zones themselves operate solely as destination points.

Figure 29 below illustrates the warehouse layout, highlighting the internal routes (blue lines) as well as the origin and destination points identified by the numerical labels described above. A color coding is adopted for clarity: origin points are marked in red, destination points in orange, and the hybrid station (Repackaging Area, both origin and destination) in green.

This graphical representation facilitates the visualization of the starting and ending locations of the material movement.

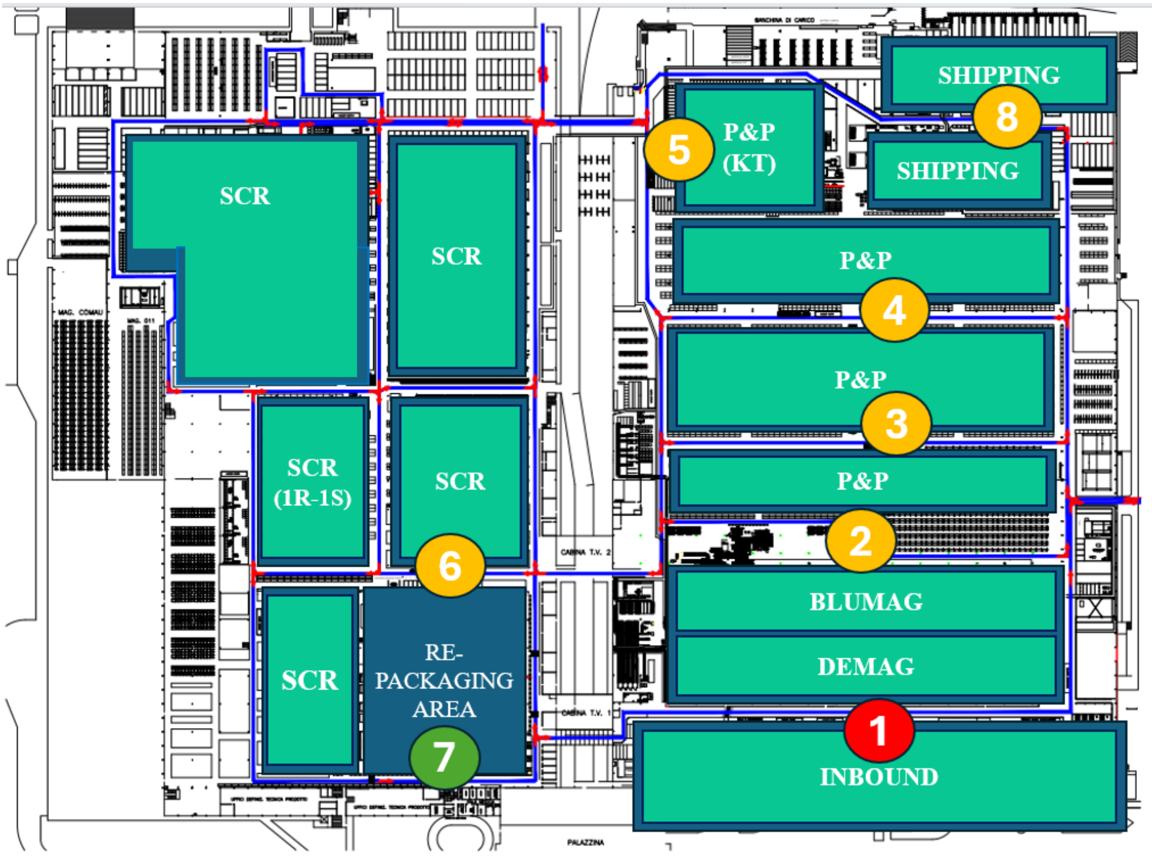

Figure 29: Internal routes and Storage Flow origin/destination points within the warehouse layout

Moreover, as illustrated in the process mapping reported in Figure 28 (Section 6.3), all routes are also performed in the opposite direction to return the empty wagon to the origin point for the subsequent loading of material to be stored, shipped, or repackaged.

The following table provides an overview of the daily frequency for each route performed within the Storage Flow, dividing the data by flow type - from Inbound and from Repackaging Area.

Origin/ Destination	REPACKAGING AREA	P&P 10	P&P 80	KT	SCR-PUTAWAY	BLUMAG-PUTAWAY	SHIPPING
INBOUND	19	3	13	1	23	4	3
REPACKAGING AREA	NA	2	12	0	0	5	0

Table 6: Material Handling Route Matrix – Storage Flow

7.2.1. Operational Information

For the analysis of the material handling flow destinated for storage, the following operational data were considered:

- Number of engines (locomotives) available in the Inflow department.
- Number of wagons available in the Inflow department.
- Number of personnel involved in the handling process.
- Number of work shifts during which material handling takes place.
- Time slots of the work shifts.

Operational configuration of the Inflow area:

- 6 engines (locomotives) and 10 wagons (in block of three) available
- 12 operators responsible for handling the tugger trains (tugger train drivers)
- 7 forklift operators responsible for loading
- 2 work shifts: first shift from 06:00 to 14:00, second shift from 14:01 to 22:00

These data provide an overview of the resources employed and the time dedicated to material handling, forming the basis for identifying opportunities to optimize and improve logistics operations.

7.2.2. Data Collection

For the analysis of the storage flow, data and measurements were collected through the completion of a standard form by the Tugger Train drivers during a two-weeks observation period covering all work shifts.

The relevant variables recorded for data collected are:

- Date
- Shift
- Departure time
- Departure location
- Arrival time
- Arrival location
- Waiting for loading (flag yes/no)
- Waiting for unloading (flag yes/no)

A total of 1.461 records were collected, subsequently processed and used to calculate process variables and KPIs.

The data were integrated with operational information on work shifts, structured as follows:

- 1st shift: from 06:00 to 14:00 (duration 480 minutes), with two breaks:
  - Short break: 08:10 – 08:20 (duration 10 minutes)
  - Long break: 11:00 – 11:50 (duration 50 minutes)
- 2nd shift: from 14:01 to 22:00 (duration 480 minutes), with two breaks:
  - Short break: 16:05 – 16:15 (duration 10 minutes)
  - Long break: 19:00 – 19:50 (duration 50 minutes)

The figure below shows the structure of the standard form:

Date	Shift	Departure Time	Departure Place	Arrival Time	Arrival Place (Destination)	Waiting For Loading YES/NO	Waiting For Unloading YES/NO

Figure 30: Empty form for Data Collection

7.2.3. KPI Analysis and Calculation

This section reports the analysis and calculation of the main KPIs and variables related to material handling process performed by the Tugger Train Drivers within the Storage Flow. The approach is based on the analysis of measured data and standard formulas defined for each indicator.

In order to calculate the KPIs of Process Time (PT) and Tugger Train Efficiency (E), it was necessary to determine two variables related to waiting time due to shifts characteristics T_w and waiting time due to loading and unloading activities $T_{u/l}$.
These variables are described and analyzed below.

<u>Variable: Waiting Time (T_w):</u>
This variable represents the operator's waiting time, measured in terms of hours/day, resulting from the beginning and end of the shift or intermediate breaks, related to specific operational needs. The calculation was made using the forms filled out by the operators, taking into consideration the operational data related to the time slots of the work shifts, described in the previous section 7.2.2.
The calculation of the T_w variable comes from the sum of four "subvariables" of waiting time, computed from the data recorded through the forms filled out by each operator by day and by shift. The "subvariables" and their calculation modes are described below:

1. **Waiting at Start Shift:**

$$T_{start\ shift} = [\text{Departure Time (First movement) - Start Time shift}] \times \text{Daily Frequency}$$

Here, the waiting time represents the average elapsed time from the start time of the shift to the time when the operator actually started the activity, by performing the first movement with the Tugger Train. The average time is then multiplied by the daily frequency with which it occurs inside the measurements (data) collected in the filled-out forms.

2. **Waiting at End Shift:**

$$T_{end\ shift} = [\text{End Time shift - Arrival Time (Last Movement)}] \times \text{Daily Frequency}$$

In this case, the waiting time refers to the period between the time when the operator ends his activity, by performing the last movement with the Tugger Train, and the official end of shift time. This waiting time is an average, that is then multiplied, according to the formula, by the daily frequency with which it occurs in the data base.

3. **Waiting during the short Break**:

$$T_{short\ break} = [\textit{Departure time of row } n+1 - \textit{Arrival time of row } n - \textit{Duration of short break}] \times \textit{Daily Frequency}$$

This formula is applied to calculate the average waiting time when a short break, with the duration of 10 minutes occurs. The waiting time is measured only if the departure time of the next handling operation (row n+1 of the filled-out form) and the arrival time of the previous handling operation (row n of the filled-out form) fall within the time interval provided for the short break. Also in this case, the average time is then multiplied by the daily frequency.

4. **Waiting during Long Break**:

$$T_{long\ break} = [\textit{Departure time of row } n+1 - \textit{Arrival time of row } n - \textit{Duration of long break}] \times \textit{Daily Frequency}$$

In this case, the calculation is done by focusing on the planned long breaks in the shift: it is calculated only if the times of the previous (row n) and next movement (row n+1) are within the established range for the long break. The multiplication of the average waiting time by the daily frequency, provides the total waiting time per day.

For the final calculation of the subsequent KPIs, specifically Process Time (PT), and Tugger Train Efficiency (E), these subvariables were aggregated using the following formula:

$$\mathbf{T_w = T_{shift\ start} + T_{shift\ end} + T_{break} + T_{long\ break}}$$

The result of the variable T_w represents the average daily waiting time (in terms of hours/day), caused by operational needs during the start/end of the shifts and the short/long breaks.

The outcomes of the calculations for T_w are presented in Table 7 below.

Variable	Average waiting time/day	Average waiting hours/day
$T_{end\ shift}$	03:56:32	3,93
$T_{start\ shift}$	02:08:53	2,13
$T_{short\ break}$	03:11:18	3,18
$T_{long\ break}$	01:31:26	1,52
T_W		**10,77**

Table 7: T_w calculation - Storage Flow

The total daily waiting time (T_W) for the Storage Flow is therefore **10,77 h/day.**

Variabile: Waiting Time for loading/unloading ($T_{u/l}$)

This variable represents the waiting time spent by the Tugger Train Drivers, measured in hours per day, linked to loading or unloading operations at a specific origin or destination point within the warehouse. As shown in the Material Handling process map (Figure 28, Section 6.3), these waiting time is classified as the sum of non-value-added activities (red boxes). Specifically, it includes waiting in queue for the availability of a parking slot, waiting for a forklift operator to become available, and waiting for the completion of loading or unloading operations, respectively at the origin or destination point. All these waiting times are primarily related to the unavailability of empty wagons. Specifically, the loading operation cannot be performed in advance if no empty wagon is available at the origin point, while the unloading operation cannot be completed in advance if the empty wagon, required to be returned to the origin point to resume the handling cycle, is not available. In this case, the Tugger Train driver is forced to wait for the "direct" unloading of material at the destination point before continuing the cycle.

Hence, this waiting time was calculated by dividing the material handling operations into four distinct categories of movement (named ***Transfers***), according to the direction and load/unload of the wagons.

- **Transfer 1 – Full Load:**
  From the Inbound area to the warehouse zones or repackaging areas, for the storage or repackaging of materials. This transfer occurs with the Tugger Train fully loaded with materials that must be unloaded at the destination point.
- **Transfer 2 – Full Load:**
  From the repackaging area to the warehouse zones, for the storage of repackaged goods.

This transfer involves a Tugger Train fully loaded with repackaged materials to be unloaded at the destination point for storage.

- **Transfer 3 – Empty Load:**
  From the warehouse zones or repackaging areas back to the Inbound department, in order to return the empty wagons and prepare them for the next loading cycle.

- **Transfer 4 – Empty Load:**
  From the warehouse zones to the repackaging area, in order to return the empty wagons and prepare them for the next material loading operation.

The waiting time due to direct loading/unloading activities was determined by first calculating the average waiting time at each origin or destination point, based on the route. This value was then multiplied by the average daily frequency of each route, resulting in the total average daily time spent on waiting for Tugger Train loading/unloading operations for each type of route. Finally, the results were summed to obtain the total daily time spent on waiting for Tugger Train loading/unloading operations for each *Transfer* type.
An example of the calculation for Transfer 1 is presented in Table 8 below.

Origin	Destination	Daily Frequency	Average Waiting Time /Route$_{x,y}$	Average Waiting Time Route$_{x,y}$/day
INBOUND	BLUMAG-PUTAWAY	4	00:07:34	00:30:15
INBOUND	REPACKAGING AREA	19	00:18:50	05:57:56
INBOUND	KT	1	00:08:20	00:08:20
INBOUND	P&P 10	3	00:05:22	00:16:07
INBOUND	P&P 80	13	00:02:42	00:35:12
INBOUND	SCR-PUTAWAY	23	00:08:44	03:20:41
INBOUND	SHIPPING	3	00:08:26	00:25:17
Total				**11:13:48**

Table 8: Example of Calculation of Loading/Unloading Time for Transfer 1 – Storage Flow

In the Table above, the first and second columns indicate the origin and destination points of the routes included in each *Transfer i*, where "i" represents each category of Transfers defined before. The origin and destination points can be generally categorized respectively with X and Y. For each route (from origin X to destination Y) the third column reports the *daily frequency*, that stands for the average number of daily movements performed along that route. This daily frequency, multiplied by the *average waiting time per each route*, reported in column 4, provides the results for the *waiting daily time* due to loading/unloading activities, for each route. This last result is reported in the last column of the Table above, and is calculated by using the following formula:

Average daily waiting time (Route x,y) = Daily Frequency (Route x,y) x Average Waiting Time (Route x,y)

The final step for the calculation of the total average daily waiting time for each transfer type, defined as $T_{u/l}$ (Transfer i), is carried out by summing the average daily waiting times of all routes. The resulting value is reported in the bottom-right cell of the table, highlighted in red. In this specific example, it represents the average waiting time for Transfer 1, defined as $T_{u/l}$ (Transfer 1).

For the calculation of the subsequent KPIs (Process Time and Tugger Train Efficiency) the average daily waiting time due to loading/unloading operations for each *Transfer i* were summed, using the following formula:

$$\mathbf{T_{u/l} = T_{u/l}\ (Transfer\ 1) + T_{u/l}\ (Transfer\ 2) + T_{u/l}\ (Transfer\ 3) + T_{u/l}\ (Transfer\ 4)}$$

Table 9 below presents the result for the aggregated value of the variable $T_{u/l}$ for the Storage Flow, resulting in **23,70 h/day**.

Transfer	Average Waiting time for loading/unloading [min/day] (AS-IS)	Average Waiting Time for loading/unloading [hours/day] (AS-IS)
Transfer 1	670,00	11,17
Transfer 2	59,00	0,98
Transfer 3	563,00	9,38
Transfer 4	130,00	2,17
Total		**23,70**

Table 9: $T_{u/l}$ Calculation – Storage Flow

KPI: Cycle Time (CT)

As described in the previous paragraph the **cycle time** represents the pure travel time required to move from point X to point Y. Specifically, it is represented by the sum of valued-added activity (green boxes) and non-value-added but necessary activity (yellow boxes) depicted in the Material Handling process map (Figure 28, Section 6.3).
Hence the CT, is the aggregation of the movement of the tugger train for the transportation of material (VA) from the origin to the destination point of the defined routes, and the

movement of the tugger train to return the empty wagon (NVAN) to the origin point to resume the handling cycle.

It was calculated by dividing the material handling flows into four types of movements (*Transfers*), as done for the calculation of waiting time for loading/unloading, based on the direction of movement and the loading/unloading status of the Tugger Train:

- **Transfer 1 – Full Load:**
  Movement of the fully loaded Tugger Train from the Inbound department to the warehouse zones or repackaging area.

- **Transfer 2 – Full Load:**
  Movement of the fully loaded Tugger Train from the repackaging area to the warehouse zones, carrying materials to be stored.

- **Transfer 3 – Empty Load:**
  Return of the empty Tugger Train from the warehouse zones or repackaging area to the Inbound deprtment, where it will be subsequently loaded with new materials.

- **Transfer 4 – Empty Load:**
  Movement from the warehouse zones to the repackaging area to return the empty Tugger Train and prepare it for the next material loading.

The table 8 below presents an example of the calculation of CT for Transfer 1.

Origin	Destination	Daily Frequency	Average Cycle Time/route	Average Cycle Time route/day
INBOUND	BLUMAG-PUTAWAY	4	00:05:58	00:23:53
INBOUND	REPACKAGING AREA	19	00:08:16	02:37:12
INBOUND	KT	1	00:11:50	00:11:50
INBOUND	P&P 10	3	00:06:13	00:18:40
INBOUND	P&P 80	13	00:03:57	00:51:23
INBOUND	SCR-PUTAWAY	23	00:06:06	02:20:24
INBOUND	SHIPPING	3	00:06:54	00:20:43
Total				**07:04:04**

Table 10: Example of Calculation of Cycle Time for Transfer 1 – Storage Flow

The Cycle Time was calculated by first determining the *average cycle time per each route from X to Y*, reported inside the 4th column of table 10. This value was then multiplied by the *daily frequency*, which represents the average number of daily movements performed for each route from X to Y (reported in the 3rd column of the table). The results of this multiplication provide the *average daily cycle time for each route from X to Y*, showed in the 5th column of the table, and carried out using the following formula:

Average daily cycle time (Route x,y) = Daily Frequency (Route x,y) x Average Cycle Time (Route x,y)

Finally, the resulting values were summed to obtain the total daily cycle time for each *Transfer* type (i), defined as $CT_{\text{transfer } i}$, reported in the bottom-right cell of the table, highlighted in red. In this specific example, it represents the average Cycle Time for Transfer 1, defined as $CT_{\text{transfer } 1}$.

For the calculation of the Process Time (PT) and Tugger Train Efficiency (E), performed in the following section, it is necessary to consider the total daily Cycle Time (expressed in hours per day) by summing the Cycle Time for each type of transfer i, using the following formula:

$$\mathbf{CT = CT_{Transfer\ 1} + CT_{Transfer\ 2} + CT_{Transfer\ 3} + CT_{Transfer\ 4}}$$

Table 11 presents the results of the CT calculation:

Transfer	Average Cycle Time/day (AS-IS)	Average Cycle Time [Hours/day] (AS-IS)
Transfer 1	07:04:04	7,1
Transfer 2	02:07:37	2,1
Transfer 3	06:51:07	6,9
Transfer 4	01:05:11	1,1
Total		**17,1**

Table 11: Cycle Time Calculation – Storage Flow

The total cycle time (CT), expressed in hours per day for the Storage Flow, is therefore as **17,1 h/day**

KPIs: Process Time (PT) and Efficiency

As previously described, **Process Time (PT)** represents the total time required to complete a material handling operation within the warehouse. This indicator is calculated as the sum of three fundamental components: waiting time caused by shift change and breaks (T_w), waiting time due to loading/unloading activities ($T_{u/l}$), and cycle time (CT), using the following formula:

$$\boldsymbol{PT = T_w + T_{u/l} + CT}$$

On the other hand, the **Tugger Train Efficiency (E)** measures the proportion of time actually spent on movement of the Tugger Train (CT) relative to the total Process Time (PT). It is expressed as a percentage ratio between the Cycle Time and the overall Process Time, using the following formula:

$$E\% = \frac{CT}{PT} \; x\, 100 = \frac{CT}{CT + Tu\_l + Tw} \; x\, 100$$

Table 12 below presents the calculation of **Tugger Train Efficiency (E)** and total **Process Time (PT)**, combining all previously calculated variables and KPIs.

KPI/Variable	Average Time [Hours/day]	%
CT	17,12	**33%**
$T_{u/l}$	23,70	46%
T_w	10,77	21%
PT	**51,58**	100%

Table 12: Results of Process Time and Tugger Train Efficiency – Storage Flow

The table shows that the overall **Process Time (PT)** amounts to **51.58 hours per day**, while the **Tugger Train Efficiency (E)** corresponds to the **33%**, evaluated through the formula described previously:

$$E\% = \frac{17,12\; h/day}{51,58\; h/day} \; x\, 100 = \frac{17,12\; h/day}{(17,12 + 23,7 + 10,77)h/day} \; x\, 100 = 33\%$$

This result indicates that only a limited portion of the total time is effectively dedicated to the movement of the wagons performed by the tugger train drivers, whereas the remaining time is absorbed by non-value-added (NVA) activities such as waiting time due to loading/unloading operations.

The Analyze phase will identify the root causes and, consequently, possible solutions to increase the Tugger Train Efficiency by partially reducing Cycle Time (VA + NVAN) and minimizing or eliminating waiting time due to loading/unloading $T_{u/l}$ (NVA). The reduction of waiting time during shift changes and breaks (T_w), which account for 21% of the process time, will be considered out of scope as it depends on specific operational requirements that cannot be eliminated, and it will be considered fixed.

KPIs: Distance Traveled (D) and Theoretical Cycle Time (CT_{th})

The distance traveled (D) analysis allows to measure the kilometers/day performed by the Tugger Train drivers during material handling operations. For the calculation of this KPI, each route (from point X to point Y) performed by the Tugger Trains for the storage flow was evaluated. Each route was considered with two types of movements, Empty-load and Full-load, as done in the analysis of the previous KPIs.

Tables 13 and 14 respectively show the results of the calculation performed for the **Distance Traveled (D)** for the Full-Load and Empty-Load movements within the Storage Flow.

Departure Point	Destination Point	Distance AS IS [mt]	Time/route	Frequency /route	Total distance/route/day [mt]	Total Time/route/day
INBOUND	KT	456	00:03:54	1	456	00:03:54
INBOUND	P&P 10	519	00:04:26	3	1557	00:13:18
INBOUND	REPACKAGING AREA	854	00:07:19	21	17934	02:33:39
INBOUND	SCR-PUTAWAY	600	00:05:08	23	13800	01:58:04
INBOUND	SHIPPING	676	00:05:47	3	2028	00:17:21
INBOUND	PP 80	305	00:02:36	13	3965	00:33:48
INBOUND	BLUMAG-PUTAWAY	552	00:04:43	5	2760	00:23:35
REPACKAGING AREA	BLUMAG-PUTAWAY	803	00:06:52	6	4818	00:41:12
REPACKAGING AREA	P&P 10	772	00:06:37	3	2316	00:19:51
REPACKAGING AREA	P&P 80	566	00:04:51	14	7924	01:07:54
Total					**57558**	**8:12:36**

Table 13: Calculation for Distance Traveled - Storage Flow – Full Load

Departure Point	Destination Point	Distance AS IS [mt]	Time/route	Frequency /route	Total distance/route/day [mt]	Total Time/route/day
KT	INBOUND	798	00:06:50	2	1596	00:13:40
P&P 10	INBOUND	1047	00:08:58	4	4188	00:35:52
REPACKAGING AREA	INBOUND	258	00:02:12	13	3354	00:28:36
SCR-PUTAWAY	INBOUND	495	00:04:14	23	11385	01:37:22
SHIPPING	INBOUND	975	00:08:21	3	2925	00:25:03
P&P 80	INBOUND	808	00:06:55	18	14544	02:04:30
BLUMAG-PUTAWAY	INBOUND	1114	00:09:32	6	6684	00:57:12
BLUMAG-PUTAWAY	REPACKAGING AREA	852	00:07:18	3	2556	00:21:54
P&P 10	REPACKAGING AREA	783	00:06:42	2	1566	00:13:24
P&P 80	REPACKAGING AREA	538	00:04:36	8	4304	00:36:48
Total					**53102**	**7:34:21**

Table 14: Calculation for Distance Traveled - Storage Flow – Empty Load

To obtain the results for the Distance Traveled (D), it was first measured the *distance for each route from X to Y*, in terms of meters, reported in the 3rd column of the tables below. Subsequently, we multiplied the distance by the *daily frequency for each route* (column 5), to identify the *total daily distance* (expressed in meters) performed daily for each route. This last calculation, reported in the 6th column of the table, was carried out using the following formula:

Total daily distance (Route x,y) = Daily Frequency (Route x,y) x Distance (Route x,y)

Finally, the total daily distances traveled for each route were aggregated to obtain the total **Distance Traveled (D)** per day for the Full-load movements and the Empty-load movements. These results are reported in the bottom row of the 6th column of the tables 13 and 14 below, highlighted in red.

The results shown in the tables indicate that Tugger Train operators travel an average of **110.7 km per day,** that represents the total **distance traveled (D)**, aggregating both the Full-Load and Empty-Load movements related to the Storage Flow.

This total includes **57.6 km per day** for Full-Load movements and **53.1 km per day** for Empty-Load movements.

The daily distance traveled was then converted into the daily time spent on these movements, corresponding to the **Theoretical Cycle Time (CT_{th})**, by using the following formula:

$$CTth = \frac{D}{Nominal\ Speed}$$

Considering a nominal Tugger Train speed of **7 km/h**, the total time spent on movements amounts to **15.8 h/day**, including **8.2 h/day** for the full-load movements and **7.6 h/day** for the empty-load movements (these data are reported at the right-bottom cell of the tables 13 and 14).

Table 15 below summarizes all these calculations, reporting the results of Distance Traveled (D) and the Theoretical Cycle Time (CT_{th}), described above.

Flow/Movement	Distance Traveled (D) [km/day]	Theoretical Cycle Time (CT_{th}) [hours/day]
Full-Load Movements	57,6	8,2
Empty-Load Movements	53,1	7,6
Entire Storage Flow	**110,7**	**15,8**

Table 15: Distance Traveled and Theoretical Cycle Time Calculation – Storage Flow

It is important to note that the Theoretical Cycle Time (CT_{th}) calculated in this analysis is slightly lower than the "real" Cycle Time (CT) calculated by the data recorded in the forms completed by the Tugger Train drivers. This discrepancy is due to the fact that the theoretical calculation does not account for possible obstacles along the routes or variations in speed, which can increase the actual travel time for each route.

For the purpose of analysis, it is useful to classify the time components associated with each KPI into **fixed and variable categories**. The **Waiting Time (T_w)** is considered fixed, as it mainly depends on operational constraints that cannot be modified, such as shift schedules or standard organizational rules. The **Theoretical Cycle Time (CT_{th})**, calculated on the basis of route distances and nominal traveling speed, is also considered fixed, since it does not take into account possible interruptions or variability along the path. Conversely, the real **Cycle Time (CT)** is regarded as variable, as it reflects the actual travel time along the predetermined routes, which may fluctuate due to temporary interruptions, congestion, or changes in driving speed. Similarly, the **Waiting Loading/Unloading Time ($T_{u/l}$)** is highly variable, as it depends on factors such as the availability of free parking slots, the presence of empty wagons, and the availability of forklift operators for handling activities. Consequently, the overall **Process Time (PT)** is composed of both fixed and variable components, combining theoretical baselines with real operational variability, thereby reflecting the complexity of material handling operations within the warehouse.

7.3. Shipping Flow

The shipping flow, as described in section 6.2., refers to the handling of packed materials from various warehouse zones to the Shipping department, where sorting and subsequent dispatch of goods take place.

Material handling operations for shipping follow the routes listed below:

- **BLUMAG-PACKING (9) – SHIPPING (8)**
- **DEMAG (10) – SHIPPING (8)**
- **SCR-PACKING (11) – SHIPPING (8)**
- **1R/1S (12) – SHIPPING (8)**

In the Shipping Flow, the Outflow zones (BLUMAG-PACKING, DEMAG, SCR-PACKING and 1R/1S), acts as origin points of the routes, while the SHIPPING department serves exclusively as destination point.
As in the case of the Storage Flow, it is useful to provide a more detailed description of each station in order to clarify their location within the warehouse and their role in the process. The **BLUMAG-PACKING station** is used to load material packed in the BLUMAG warehouse that must be transferred to the Shipping Department. It is located near the BLUMAG-PUTAWAY station, due to the proximity between the packing area and the loading points of the automated warehouse. The **DEMAG station** is positioned close to the packing area of the DEMAG warehouse. As noted in the analysis of the Storage Flow, this station is not considered part of the storage routes, since its loading area is located very close to the Inbound Department where the material is prepared for storage. The **SCR-PACKING station** is located next to the packing area of the SCR warehouse, while the **1R/1S station** is situated inside the SCR warehouse itself. The latter corresponds to a sub-zone of the SCR area and, as described in Section 4.2.5.3, it is analyzed separately from the other SCR sub-zones, since it follows a specific operational flow within the Shipping Flow, with a dedicated packing station and a different route. Finally, the **SHIPPING station** is the same already described for the Storage Flow (specifically in relation to the cross-docking process).
As discussed in Section 4.2.5.4, the P&P warehouse zone is considered out of scope for the Shipping Flow, since its packing area is located in close proximity to the Shipping Department. For this reason, no stations for this warehouse zone are present for the Shipping Flow.

Figure 31 below illustrates the layout of the warehouse, highlighting the internal routes, represented by blue lines, and the origin and destination points of the Shipping Flow identified by numerical labels reported above. The same color coding used for Storage flow was adopted.

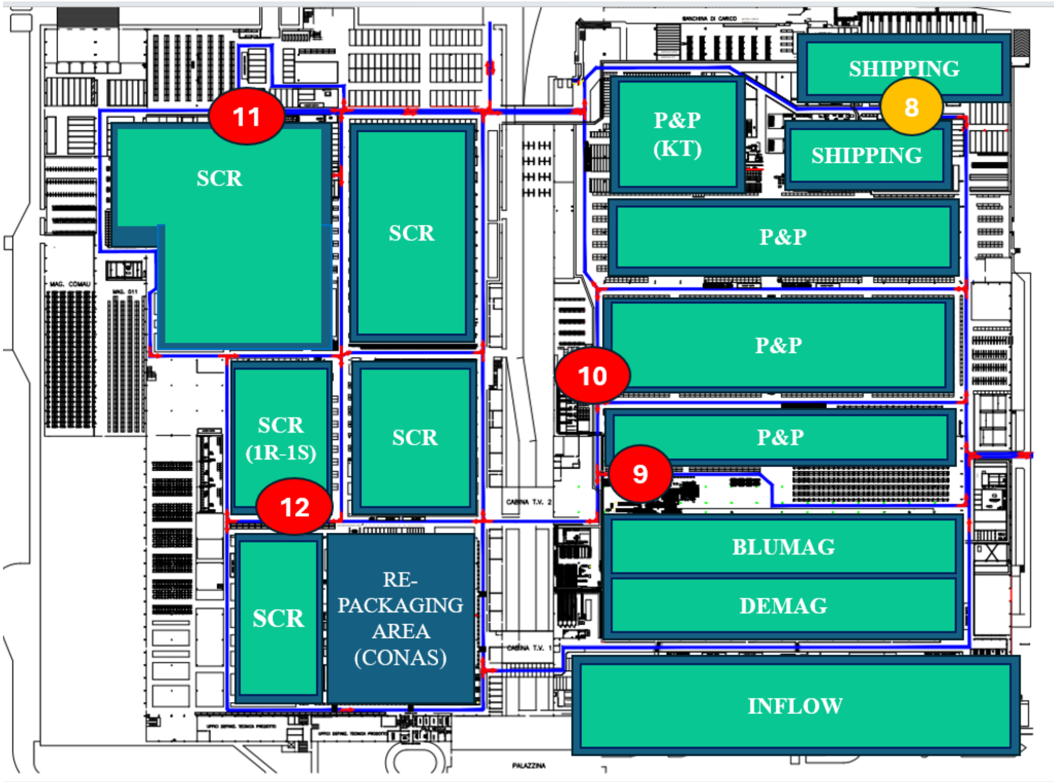

Figure 31: Internal routes and Shipping Flow origin/destination points within the warehouse layout

Furthermore, as represented in the process map reported in Figure 28 (Section 6.3), all routes are also performed in the reverse direction, to return the empty Tugger Train to the departure area for the next material loading cycle. Additionally, each route follows a fixed, predefined path due to the internal traffic layout of the warehouse.

As with the storage flow, the table 16 below outlines the shipping routes, showing origin, destination, and daily frequency for each movement.

Origin/Destination	SHIPPING
BLUMAG-PACKING	11
DEMAG	10
SCR-PACKING	29
1R/1S	16

Table 16: Material Handling Route Matrix – Shipping Flow

7.3.1. Operational Information

For the Shipping flow, the same operational data used for the storage flow were considered, including the number of engines (locomotives), number of wagons, number of operators, number of shifts, and shift time slots.

The operational configuration for the shipping flow is as follows:

- 2 engines (locomotives) and 9 wagons available
- 6 Tugger Train operators
- 6 forklift drivers assigned to unloading activities
- 3 work shifts: first shift from 06:01 to 14:00, second shift from 14:01 to 22:00, and third shift from 22:01 to 06:00

As with the storage flow, this data provides an overview of the resources involved and the time dedicated to material handling process.

7.3.2. Data Collection

Data related to the shipping flow were collected using the same methodology adopted for the analysis of the storage flow, as described in section 7.2.2. Specifically, the same standardized form was used for data recording, and the same key variables were analyzed: date, shift, departure time and location, arrival time and location, presence of waiting time for loading, and presence of waiting time for unloading. For the Shipping flow, a total of 1.239 records were collected.

The structure of the form and the details of the variables considered are shown in the empty form template (Figure 30), which served as a reference tool during the observation period.

7.3.3. KPI Analysis and Calculation

As well as the storage flow, before analyzing and calculating the identified KPIs, it was first necessary to calculate key variables. In this paragraph it will be presented the calculation of these variables and the KPIs defined before.

Variable: Waiting Time (T_w)

This variable was considered, as in the analysis of the storage flow, based on the forms filled out by the Tugger Train operators in the Shipping department.

Similarly to the storage flow, waiting time was calculated in hours per day, as the sum of the following sub-variables $T_{shift\ end}$, $T_{shift\ start}$, T_{break} , $T_{long\ break}$. The methodology used to evaluate these sub-variables is the same described for the Storage Flow.

The results for the calculation of the daily waiting time (T_W) is presented in Table 17 below.

Variable	Average waiting time/day	Average waiting hours/day
$T_{end\ shift}$	01:37:24	1,62
$T_{start\ shift}$	01:45:48	1,75
$T_{short\ break}$	01:21:00	1,35
$T_{long\ break}$	01:26:36	1,43
T_W		**6,15**

Table 17: T_w Calculation - Shipping Flow

For the calculation of the subsequent KPIs, specifically the Process Time and the Tugger Train Efficiency, the total daily waiting time (expressed in hours per day) was calculated using the following formula:

$$\mathbf{T_W} = T_{shift\ end} + T_{shift\ start} + T_{break} + T_{long\ break} = \mathbf{6{,}15\ h/day}$$

<u>Variable: Waiting Time for loading/unloading ($T_{u/l}$)</u>

As well as for the storage flow, the variable $T_{u/l}$ represents the time spent by the Tugger Train Driver to wait for the "direct" loading or unloading operations of a Tugger Train at a specific origin or destination point within the warehouse, measured in terms of hours per day. The concept is the same used for the storage flow, since it represents the waiting times which occur when the loading and/or unloading operations cannot be performed in advance due to the unavailability of an empty wagon at the origin and destination stations.
Unlike the Storage flow, the Shipping flow includes only two categories of Transfers:

- **Transfer 1 – Full Load:**
  From the warehouse Outflow zones to the Shipping department. This transfer involves a Tugger Train fully loaded with material that has been picked and packed in the Outflow areas and must be transported and unloaded in the Shipping area for sorting and dispatch.
- **Transfer 2 – Empty Load:**
  From the Shipping department back to the warehouse Outflow areas, to return the empty Tugger Train and prepare it for the next material loading cycle.

As in the storage flow, this waiting time was determined by first calculating the average time for origin or destination point of each type of route (from X to Y). This value was then multiplied by the daily frequency of each route, resulting in the total daily time spent on waiting for loading/unloading operations for each route from X to Y. Finally, the results were summed to obtain the total daily time spent on waiting for Tugger Train loading/unloading operations across both *Transfer* types.

The result of the calculation for the variable $T_{u/l}$ is shown in Table 18. The waiting time associated to loading and unloading activities was considered, as for the storage flow, in terms of hours per day by summing the times for each type of transfer i, as described in the following formula:

$$\mathbf{T_{u/l}} = T_{u/l} \text{ Transfer 1} + T_{u/l} \text{ Transfer 2} = \mathbf{13{,}99\ h/day}$$

Transfer	Average Waiting time for loading/unloading [min/day] (AS-IS)	Average Waiting time for loading/unloading [hours/day] (AS-IS)
Transfer 1	485	8,08
Transfer 2	354,1	5,90
Total		**13,99**

Table 18: $T_{u/l}$ Calculation - Shipping Flow

<u>KPI: Cycle Time (CT)</u>

As for the storage flow, this KPI represent the time spent to move from point A to point B within the internal material handling process. It is composed by both value-added activities and non-value added but necessary activities, highlighted in the process map, reported in Figure 28 (Section 6.3), green boxes and yellow boxes. As for the storage flow, it in fact represents the movement of the tugger train to transport material for the origin to the destination of the specific route and the movement to return the empty wagon from the destination to the origin point to resume the handling cycle for that specific route.

For the calculation of the **cycle time (CT)** the Shipping flow was divided into two categories of transfers:

- **Transfer 1 – Full Load:**
  Movement of the loaded Tugger Train from the Outflow zones to the Shipping department, transporting material ready for dispatch.
- **Transfer 2 – Empty Load:**
  Return of the empty Tugger Train from the Shipping area back to the Outflow areas, where it will be subsequently loaded with new material to be shipped.

As in the storage flow, the cycle time was calculated by first determining the average cycle time for each route from X to Y. This value was then multiplied by the daily frequency of each route, in order to calculate the total daily cycle time for each route type. Finally, the results were summed to obtain the total daily cycle time for each *Transfer* category.
The Cycle Time was considered in terms of hours per day, by summing the cycle time for each type of transfer i, as shown in Table 19 and described by the following formula:

$$\mathbf{CT} = CT_{\text{Transfer 1}} + CT_{\text{Transfer 2}} = \mathbf{12{,}63\ h/day}$$

Transfer	Average Cycle Time/day (AS-IS)	Average Cycle Time [Hours/day] (AS-IS)
Transfer 1	06:34:36	6,57
Transfer 2	05:49:20	5,82
Total		**12,63**

Table 19: Cycle Time Calculation – Shipping Flow

<u>KPIs: Process Time (PT) and Efficiency (E)</u>

Similarly to the storage flow, the **Process Time (PT)** and **Tugger Train Efficiency (E)** were analyzed.

Table 20 below shows the results for PT and E, combining the previously calculated KPIs and variables.

KPI/Variable	Average Time [Hours/day] AS-IS	%
CT	12,63	**39%**
$T_{u/l}$	13,99	43%
T_w	6,15	19%
PT	**32,77**	

Table 20: Results of Process Time and Efficiency – Shipping Flow

The table shows that the overall **Process Time (PT)** amounts to **32.77 hours** per day, while the **Tugger Train Efficiency (E)** is **39%**. This indicates that, also for the Shipping flow, only a limited portion of the time is actually spent on the operational movement of the tugger train, compared to the total time spent for the overall process that includes also NVA times, such as T_w and $T_{u/l}$.
In the A*nalyze phase*, we will identify the causes and potential solutions to eliminate or reduce the time spent on non-value-added activities, as well as the time spent for NVAN. However, reducing waiting times (due to start/end of shift and breaks), as well as for the storage flow, will be considered out of scope.

KPI: Distance Traveled (D) and Theoretical Cycle Time (CT_{th})

For the calculation of the **Distance Traveled (D)** of the **Shipping Flow**, the routes described in paragraph 7.3 were considered, evaluating both *Full-Load* and *Empty-Load* movements. The analysis was carried out using the same methodology applied to the storage flow.

The following tables, 21 and 22, present the results of the distance traveled calculations for both Full-load and Empty-load flows.

Departure Point	Destination Point	Distance AS IS [mt]	Frequency /route	Total distance/route/day [mt]	Total Time/route/day
DEMAG	SHIPPING	514	9	4626	00:39:36
BLUMAG-PACKING	SHIPPING	737	10	7370	01:03:10
SCR-PACKING	SHIPPING	337	29	9773	01:23:37
1 R/1 S	SHIPPING	755	16	12080	01:43:28
Total				**33849**	**4:49:51**

Table 21: Calculation For Distance Traveled - Shipping Flow – Full Load

Departure Point	Destination Point	Distance AS IS [mt]	Frequency /route	Total distance/route/day [mt]	Total Time/route/day
SHIPPING	DEMAG	357	11	3927	00:33:33
SHIPPING	BLUMAG-PACKING	359	11	3949	00:33:44
SHIPPING	SCR-PACKING	570	27	15390	02:11:51
SHIPPING	1 R/1 S	692	14	9688	01:22:50
Total				**32954**	**4:41:58**

Table 22: Calculation For Distance Traveled - Shipping Flow – Empty Load

The results from the above tables show that the tugger train drivers travel an average of **66.7 km per day** to complete all routes in the Shipping flow. This total includes **33.8 km per day for Full Load** movements and **32.9 km per day for Empty Load** movements.

The daily kilometers traveled were then converted into the average daily time spent on movements, corresponding to the Theoretical Cycle Time. Considering an average tugger train speed of **7 km/h**, the total time spent on movements amounts to **9.5 hours per day**, including **4,8 h/day** for the full-load movements and **4,7 h/day** for the empty-load movements.

Table 23 below summarizes all these calculations, reporting the results of Distance Traveled (D) and the Theoretical Cycle Time (CT_{th}), described above.

Flow/Movement	Distance Traveled (D) [km/day]	Theoretical Cycle Time (CT_{th}) [hours/day]
Full-Load Movements	33,8	4,8
Empty-Load Movements	32,9	4,7
Entire Storage Flow	**66,7**	**9,5**

Table 23: Distance Traveled and Theoretical Cycle Time Calculation – Shipping Flow

As well as for the storage flow, the theoretical cycle time (CT_{th}) is slightly lower than the cycle time (CT) calculated before. This difference is due to the theoretical calculation not accounting for obstacles or speed variations along the routes.

KPI: Delivery Inaccuracy Rate (DIR)

This KPI evaluates the **inaccuracy of internal deliveries**, meaning the transfer of packages from the outflow zones, where materials are picked and packed, to the Shipping department, where goods are prepared for dispatch to customers.

The indicator measures, as percentage, the number of packages that were missing in the Shipping area at the time of truck loading, compared to the total number of packages that should have been loaded, and it's calculated using the following formula:

$$\boldsymbol{DIR = (n^\circ\ packages\ searched \div n^\circ\ packages\ loaded) \times 100}$$

To obtain a reliable value for this KPI, the average of all DIR values calculated on a daily basis was considered, using data collected through a form filed out by the forklift operators of the Shipping Department. This form included the following information:

- Truck loading date
- Total number of packages to be loaded onto the truck
- Number of packages not yet available in the Shipping area at the time of loading

The collected data yields a final value corresponding to the average of the daily **Delivery Inaccuracy Rate (DIR)**, which amounts to **59%**.

During the analyzed truck loading process, represented in the flow chart reported in Figure 32, when shipping operators don't find a package in the Shipping Department, they search in the different outflow areas to find and load it onto the truck, ensuring customer delivery compliance. This search results in significant **time waste**, highlighted in the process map (Figure 32) with a red circle.

To better quantify the impact of the DIR on the efficiency of the handling and truck loading process, the inaccuracy rate was converted into daily hours spent searching for packages not delivered on time to the Shipping department.

For this analysis, process observations were conducted measuring the time taken for the following steps:

- **Step 1: Set-up** – Receiving the loading document from the shipping office and verifying the packages to be loaded via monitor.
- **Step 2: Loading and package search** – From completing the monitor verification to loading the pallet onto the truck.
- **Any anomalies** – Waiting times due to inactivity, congestion, or damaged packages.

Table 24 shows the measurements collection for the three steps described above, included in the truck loading process.

# Observations	**obs 1**	**obs 2**	**obs 3**	**obs 4**	**obs 5**	**obs 6**	**obs 7**	**obs 8**	**obs 9**	**obs 10**	**obs 11**	**obs 12**	**obs 13**	**obs 14**	**Average**
# Workers	1	1	2	3	4	4	5	5	5	5	5	5	5	5	
Step 1 [sec]: Set-up - Receive the loading document from the shipping office and perform a check on the monitor of the packages to be loaded.	102	54	250	115	229	54	1267	632	415	386	807	263	501	876	
Step 2 [sec]: Loading and searching for packages. From the completion of the monitor check to the loading of the pallet onto the truck.	833	3420	14100	2719	6262	1486	37509	17185	7936	7388	19389	5025	9519	23342	
Anomaly [sec]: Waiting (inactivity, congestion, etc.)				101,24											
Anomaly [sec]: Damaged package					32										
Step1+ Step 2 [sec]	935	3474	14350	2834	6491	1540	38776	17817	8352	7775	20196	5287	10020	24218	
N° of Packages searched [#]	23	8	147	37	120	18	217	120	107	117	133	150	64	200	
CT step 1 [sec/package]	4	7	2	3	2	3	6	5	4	3	6	2	8	4	4
CT step 2 [sec/package]	36	428	96	73	52	83	173	143	74	63	146	33	149	117	119
CT step1+step2 [sec/package]	**41**	**434**	**98**	**77**	**54**	**86**	**179**	**148**	**78**	**66**	**152**	**35**	**157**	**121**	**123**

Table 24: Data collection for truck loading process

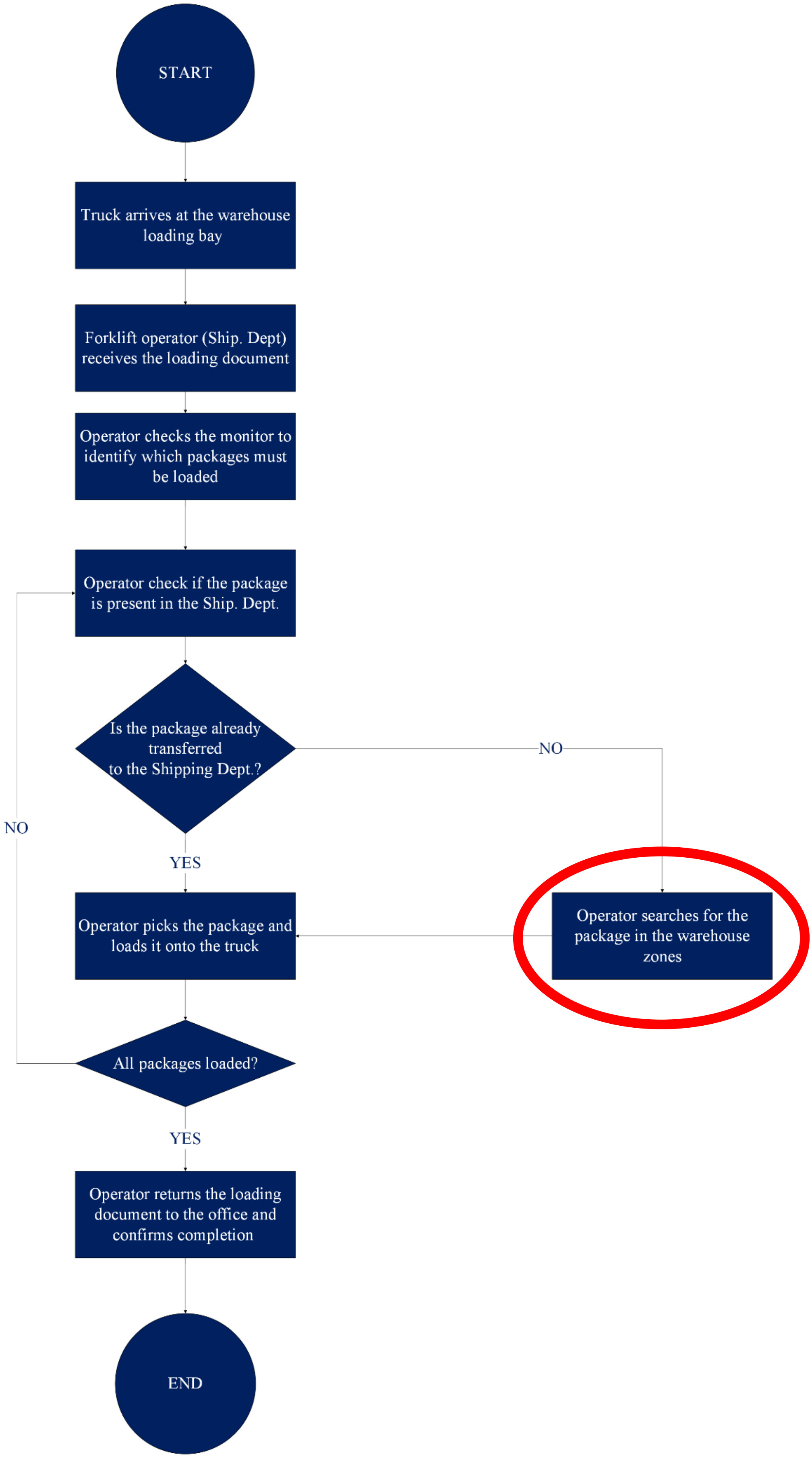

Figure 32: Flow Chart Truck Loading Process

Based on the recorded observations, the average time required to complete Step 2—comprising both the search for and loading of each package onto the truck—is **119 seconds per package**. Given a **Delivery Inaccuracy Rate (DIR) of 59%**, it can be reasonably inferred that approximately 59% of this time is attributable to the package searching activity. Consequently, the average time spent searching for a single package is estimated to be **70.03 seconds**. This value was then multiplied by the average number of packages searched per day to estimate the total daily time allocated to this activity, as well as its proportional impact on the overall truck loading process. The number of packages searched daily corresponds to 59% of the total number of packages loaded and shipped. An analysis of a dataset, extracted for the period January–June 2024, indicates an average daily shipment volume of 5,971 packages. Applying the 59% search rate yields an estimated **3,514 packages searched per day**.

By multiplying the average search time per package (70.03 seconds) by the daily number of packages searched, the total time spent on this activity amounts to approximately **68.36 hours per day**. This represents the **28%** of the total time required for the truck loading process. Table 25 reports all the data about the calculations described above.

CT loading [sec/packages]	123
% inefficiency + anomalies	20%
PT loading [sec/packages]	148
Total time for trucks loading [sec/day]	883071
Total time for trucks loading [hours/day]	245
Time spent for packages reasearch [sec/package]	**70,03**
N° of packages delivered/day	5971,91
N° of packages searched/day	**3514,35**
Time spent for searching packages [sec/day]	246098,35
Time spent for searching packages [hours/day]	***68,36***
Time spent for searching [%]	**28%**

Table 25: Summary of package searching time estimation

The analysis conducted in this chapter has made it possible to map and quantify the current performance of the material handling process using a set of performance indicators. By calculating and interpreting the selected KPIs, such as Process Time, Cycle Time, and Tugger Train Efficiency, it has been possible to identify relevant inefficiencies and understand their impact on the overall flow. Table 26 below, summarizes the **results for each variable and KPI in the AS-IS scenario**, with a comparison between the **Storage** and the **Shipping** Flow.

Variable/KPI	Storage Flow	Shipping Flow
T_w [hours/day]	10,77	6,15
$T_{u/l}$ [hours/day]	23,70	13,99
CT [hours/day]	17,11	12,63
PT [hours/day]	51,58	32,77
E [%]	33%	39%
D [kilometers/day]	110,7	66,7
CT_{th} [hours/day]	15,8	9,5
DIR [%]	/	59%

Table 26: Variables and KPIs results in the AS-IS scenario

These results serve as a solid foundation for the next phase of the project, which will focus on identifying the root causes of the inefficiencies observed and proposing targeted solutions for improvement. The following chapters present a causal analysis and outlines potential interventions aimed at optimizing and increasing the overall performance of the material handling process inside Kuehne-Nagel Turin Warehouse.

8. Analyze Phase

The previous analysis provides a clear understanding of the inefficiencies that have the greatest impact on the overall performance of the material handling process, considering both the storage and shipping flows.

8.1. Root Causes Identification

As highlighted in the evaluation of the AS-IS KPIs, the Tugger Train Efficiency, defined as the proportion of effective equipment movement time (Cycle Time) between departments within the Turin Warehouse, relative to the Total Process Time (which includes additional activities such as loading, unloading, and waiting), is notably low in both flows. Specifically, this Tugger Train Efficiency is measured at **33%** for the Storage Flow and **39%** for the Shipping Flow.

This low value of the KPI is mainly attributable to two major categories of waste: **Waiting** and **Extra-Processing**, which manifest in the following ways:

- **Unavailability of designated Tugger Train parking spots in specific stations**: This condition often forces forklift operators to perform direct loading/unloading operations, in turn generate waiting times for Tugger Train drivers, as they must remain idle until the loading/unloading process is completed. Moreover, when the Tugger Train is positioned in transit aisles rather than in the appropriate parking areas, an additional handling operation is required to reposition the material, resulting in extra-processing.
- **Unavailability of empty wagons for full/empty exchanges**: In this case the Tugger Train driver must wait for a forklift operator to load/unload the wagon, since he cannot perform the immediate full/empty exchange, leading again to long idle time (Waiting).
- **Misalignment of break times between departments**: The lack of synchronization between break periods in the Shipping and Outflow departments results in temporary downtime, during which Outflow areas accumulate material that cannot be loaded onto stationary Tugger Trains wagons, since are already full of material. This leads to the creation of additional buffer areas and duplicate handling operations, as material is first deposited and then later reloaded. This double handling represents a waste associated to Extra-Processing.

The first two inefficiencies significantly influence the waiting time due to loading/unloading activities **($T_{u/l}$)** described in the previous KPI measurement section. This time accounts for **23.7 hours/day** in the Storage Flow, **46% of its total process time**, and **13.99 hours/day** in the Shipping Flow, **43% of its total process time**.

In addition to the previously discussed inefficiencies related to Waiting and Extra-Processing, further waste has been identified in the form of **Transport**. This inefficiency directly affects value-added portion of time spent for the material handling process, represented by the **Cycle Time (CT)**.

The most significant contributor to this type of waste is the excessive length and suboptimal configuration of the internal routes between departments within the Turin warehouse. These routes are not only long in terms of physical distance but are also inefficient in terms of daily travel frequency and operational flexibility. As confirmed by the **Distance Traveled**, Tugger Train drivers cover an average of **110 km/day** for the Storage Flow and **66.7 km/day** for the Shipping Flow.

A further contributing factor to the inefficiency in cycle time is the **rigidity of the routing system**. Each Tugger Train operator follows a predefined, fixed route, connecting two specific points of the warehouse, without the possibility of adapting their path based on operational needs. As a result, every trip consists of a full-load transfer followed by a return trip with an empty wagon, required to resume the material flow from the origin station. This structural inflexibility leads to creation of **non-value-added but necessary travel time** during the return trip and increases the overall cycle time.

Moreover, this rigid segmentation contributes to **resource imbalance** across departments, creating bottlenecks in some warehouse areas and idle time in others. For instance, in the afternoon, when the Shipping Department is heavily engaged in loading trucks for final dispatch, the Tugger Train operator from the Storage Flow, who may have completed their tasks and is waiting for a new load, remains inactive. Despite this available capacity, the operator cannot support the Shipping Department due to the separation of workflows and resources. This missed opportunity leads to unutilized labor and handling capacity in one area, while another area is overburdened and unable to complete all required material movements in time.

This **lack of routing flexibility**, together with the **strict separation of the two flows** (each with dedicated equipment and personnel), results in excessive **waiting times**, **bottlenecks**, and general inefficiencies across the entire internal material handling process.

Finally, the last KPI analyzed in the measurement phase, the **Delivery Inaccuracy Rate (DIR)**, highlights a further critical inefficiency within the Shipping Flow, primarily linked to the waste of **Transport/Movement**. This waste is generated by the significant amount of time shipping operators spend searching for packages in the outflow areas to complete the truck loading process. As reported in the previous dedicated section, shipping operators spend on average **68.36 hours per day** searching for packages in the outflow zones, which represents **28%** of the total truck loading process time.

This excessive searching time can be interpreted as unnecessary transport and movement of operators within the warehouse. The root cause is that packaged items from the outflow areas do not arrive in time at the shipping department, as evidenced by the Delivery Inaccuracy Rate of **59%**.

This low level of internal delivery precision can be attributed to two main factors:

- **The overall inefficiency and discontinuity of the material handling process**, which is not characterized by a continuous and regular flow, particularly for materials classified with high rotation (Class A). In the AS-IS process, material can only be transferred to the Shipping Department once the Tugger Train has reached full saturation. This operating mode generates a discontinuous flow: during certain time slots no material reaches the Shipping Department, since Tugger Trains are still being loaded, while in other moments large quantities of material arrive simultaneously, creating bottleneck and congestion. Such variability is especially problematic for high-rotation items, which generate a high number of order lines and shipping units and therefore should be moved continuously throughout the day.
- **The absence of a real-time tracking system**: once items are packed and labeled, no further tracking occurs throughout their internal movement. As a result, shipping operators who are missing specific packages required for truck loading lack visibility regarding the exact status and location of the material (whether it is stored in a buffer area, loaded onto a Tugger Train, in transit to the Shipping Department, or already unloaded and awaiting sorting). This lack of visibility leads operators to spend an excessive amount of time searching for packages without knowing where or how to search for them, thereby exacerbating inefficiencies related to unnecessary transport and movement within the warehouse.

To conclude the root cause analysis, a **Fishbone Diagram (Ishikawa Diagram),** reported in Figure 33, was developed to provide a structured and visual representation of the underlying causes contributing to the inefficiencies observed in the internal material handling process.

The construction of the diagram was carried out during a dedicated cross-functional briefing session**,** involving representatives from all departments affected by the material handling process, Inflow, Outflow, and Shipping departments. The objective of the session was to consolidate the insights gained during the data collection and KPI measurement phase, and to ensure a shared understanding of the current inefficiencies.
The resulting diagram groups the identified causes into six categories: **Process Design, Layout**

and Routing, Resource Availability, Information and Traceability, Planning and Scheduling, and Flow Organization. Within each category, specific root causes are detailed, which directly or indirectly impact key performance indicators. This analysis supports the definition of targeted improvement actions in the subsequent phases of the project.

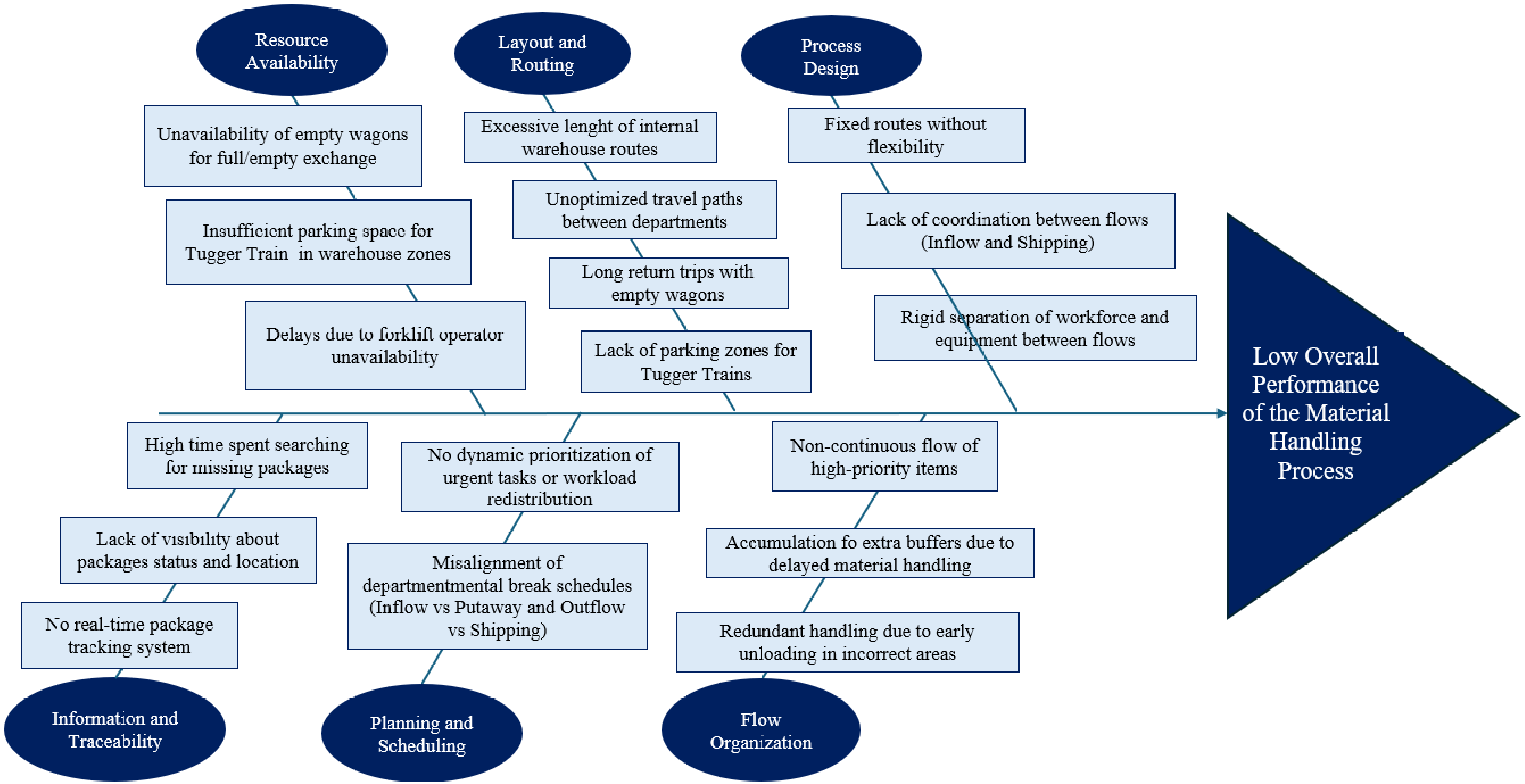

Figure 33: Ishikawa Diagram

8.2. Failure Mode and Effects Analysis (FMEA)

The previous analysis highlighted the wastes and inefficiencies identified in the material handling process at the Kuehne+Nagel warehouse in Turin. To obtain a clearer understanding of these ineffectiveness and their impact on the overall process, the project team carried out an analysis based on the Failure Modes and Effects Analysis (FMEA), which is reported and explained in this section.

As defined by Bluvband et al. (2009), the FMEA is a proactive tool developed to identify, evaluate, and prevent product and/or process failures.
In this case study, the approach is closely aligned with the model proposed by Cagliano et al. (2011), in which the use of FMEA is combined with risk analysis and lean tools, such as process mapping and waste identification. The article *"A systemic methodology for risk management in the healthcare sector"*, written by Cagliano, Grimaldi, and Rafele, demonstrates how the integration of these elements provides a comprehensive and systemic view of operational risk, making FMEA an important tool for risk management and continuous improvement. Although originally applied in the healthcare field, this methodological structure can be fully adapted to logistics processes, such as the project analyzed in this thesis.

Specifically, the FMEA developed and reported in this work (Table 27), concerning the internal material handling process at the Turin Kuehne+Nagel warehouse, was used as the connection phase of a structured approach that included:

- Process mapping,
- Identification of inefficiencies through the classification of NVA, NVAN, and VA activities,
- Identification of root causes,
- Association of each failure mode with the type of waste generated,
- Measurement of the impact on the KPIs defined and evaluated in the "Measure" phase of the project,
- Definition of improvement solutions.

Table 27 summarizes this information, providing a clear overview of the process under study and supporting the identification of targeted solutions for improvement.

Failure Mode (Inefficiency)	Process/Activity	Root Cause	Waste	KPI	Proposed Solution
Excessive internal transport time	Movement of the Tugger Train from point X to point Y of the routes for both the *Storage and Shipping Flow*	Travel paths excessively long	Transport	D, CT, CT_{th}	(1) Redesign of the internal routes
Increased waiting time during loading/unloading activities	Waiting of the Tugger Train drivers for loading/unloading activities at the origin or destination point of the routes for both the *Storage and Shipping Flow*	Unavailability of empty wagons and parking slots in the Tugger Train stations inside the warehouse	Waiting	$T_{u/l}$, E%, PT	(2) Introduce hook/unhook stations
Delivery inaccuracies at the Shipping department	Truck loading process, which involves searching for packages to be shipped that must be moved from the outflow areas through the *Shipping Flow*	Non continuous Flow	Transport/ Waiting	DIR	(3) Integrate system to ensure continuous flow during the day, integrated with a real-time tracking
High time spent searching for packages	Truck loading process, which involves searching for packages to be shipped that must be moved from the outflow areas through the *Shipping Flow*	Lack of real-time tracking and visibility and Non continuous Flow	Transport/ Movement	DIR, Searching Time	(4) Implement real-time tracking system for material loaded and transported by tugger trains
Inefficient use of equipment and workforce	The entire handling material process	Rigid separation of the Storage and Shipping Flow	Waiting	PT → specific indicators TBD	(4) Introduce unified mission system with dynamic task queues
Material accumulation and redundant handling	Preparation and loading of material onto wagons for the next movement, that regards both the *Storage and Shipping Flow*	Misalignment of departmental break schedule	Extra-processing	T_w, $T_{u/l}$, PT	(5) Realign departmental break schedules

Table 27: FMEA

8.3. Identification of Improvement Opportunities and Proposed Interventions

After the description of the main root causes identified and the corresponding potential solutions aimed at addressing these causes, the targeted interventions will be briefly described in this section, with an overview for each of them.

This overview provides for each solution its operational purpose, current status within the project, and the expected contribution to the overall optimization of the internal material handling process.

Some of the solutions has been implemented and tested during the execution of this thesis, allowing for the evaluation of their actual impact on the process during the Control Phase (chapter 10). Other solutions are either currently being implemented or planned for future deployment in the coming months. For these latter cases, the Improve phase (chapter 9) will focus on a qualitative analysis of the proposed solution and the expected benefits, with the understanding that further improvements may be achieved progressively as implementation advances over time.

Redesign of Internal Transport Routes (1)

The purpose of this solution is to optimize internal routes, thereby reducing excessive transportation time caused by unnecessarily long or suboptimal paths. Route optimization enables more rational movement patterns and contributes to a reduction in the overall Cycle Time (CT). This solution was implemented in July 2025 and is currently operational, with its measurable impacts being assessed during the Control phase.

Introduction of Hook/Unhook Stations (2)

This solution aims to reduce waiting times at the origin and destination points of the material handling flow, which arise from direct loading and unloading activities, caused by the unavailability of immediate full/empty wagon exchanges. The solution involves the implementation of a hook/unhook configuration at all possible stations within the warehouse. It was implemented in July 2025, simultaneously with the redesign of internal routes, and its performance will be monitored through TO-BE KPI measurements during the Control phase.

Introduction of Autonomous Mobile Robots (3)

To enable a continuous flow of high-rotation materials, particularly from outflow zones to the shipping area, the adoption of Autonomous Mobile Robots (AMRs) has been proposed. These robots are intended to address inefficiencies caused by delays in internal deliveries of packages to the shipping department, reducing manual package retrieval and eliminating unnecessary travel and searching time by shipping operators and forklift drivers. The analysis of the AMR system implementation is currently ongoing within the project timeline, with a pilot test and full deployment scheduled for November-December 2025.

Implementation of a Unified Mission Management and Tracking System for Tugger Trains (4)

This solution is currently in the initial study phase, consisting of a preliminary proposal, with implementation planned for 2026. In this work, only a preliminary analysis will be carried out. The solution involves the implementation of a system capable of generating dynamic missions within a work queue and tracking the material loaded onto Tugger Trains, providing full visibility of material status. This system is expected to eliminate inefficiencies and waiting times caused by the current imbalance of resources between the storage and shipping flows, which are currently managed completely separately. Furthermore, the solution will reduce the time spent by shipping forklift operators searching for packages that do not arrive on time from outflow departments, thereby improving the overall efficiency of the final shipping process.

Synchronization of Break Periods (5)

The misalignment of departmental break schedules, which creates downtime and material accumulation in buffer areas, is one of the reasons for inefficiency found in the AS-IS analysis. To guarantee constant operational coverage across departments the alignment of the breaks schedule is one of the possible solutions.
However, this solution will not be discussed further in this work, as it primarily concerns HR management and falls outside the scope of the topics addressed in this study.

9. Improve Phases

In this section, each solution identified in the previous section, either already implemented or currently in the process of being implemented, is presented in detail, together with the corresponding analysis and the expected impacts on process efficiency.

9.1. Redesign of internal routes

The solution (1), reported in the FMEA analysis, was the first to be studied and implemented, as it required only minimal investment and had a purely operational impact. The project team carried out a systematic review of all routes currently performed by the Tugger Trains during movement in the material handling process between different origin and destination points of the warehouse.

The objective of this intervention was to reduce the value-added and non-value associated but necessary time spent for the pure movement of wagons from origin point (X) to the destination point (Y) to transport material, and the opposite movement from destination to the origin point to return the empty wagon. Consequently, its implementation directly influences three key performance indicators (KPIs) defined and measured in the *Measure* phase: **Cycle Time (CT)**, representing the effective travel time, **Distance Traveled (D)**, and **Theoretical Cycle Time (CT_{th})**.

During the analysis phase, all existing routes were carefully evaluated for both the Storage and Shipping flows, with the purpose of identifying potential improvements in terms of path optimization and overall travel efficiency. Figure 34 reports the AS-IS layout of the Turin warehouse, highlighting the internal routes and the origin/destination point (with the numerical labels described in the previous sections), prior to the implementation of the solution.

In addition, the layout highlights the most critical warehouse areas (with red circles), characterized by the least efficient routes. This visual representation provides a clearer understanding of the section of the warehouse that will be primarily targeted for route revision and optimization within the framework of this solution.

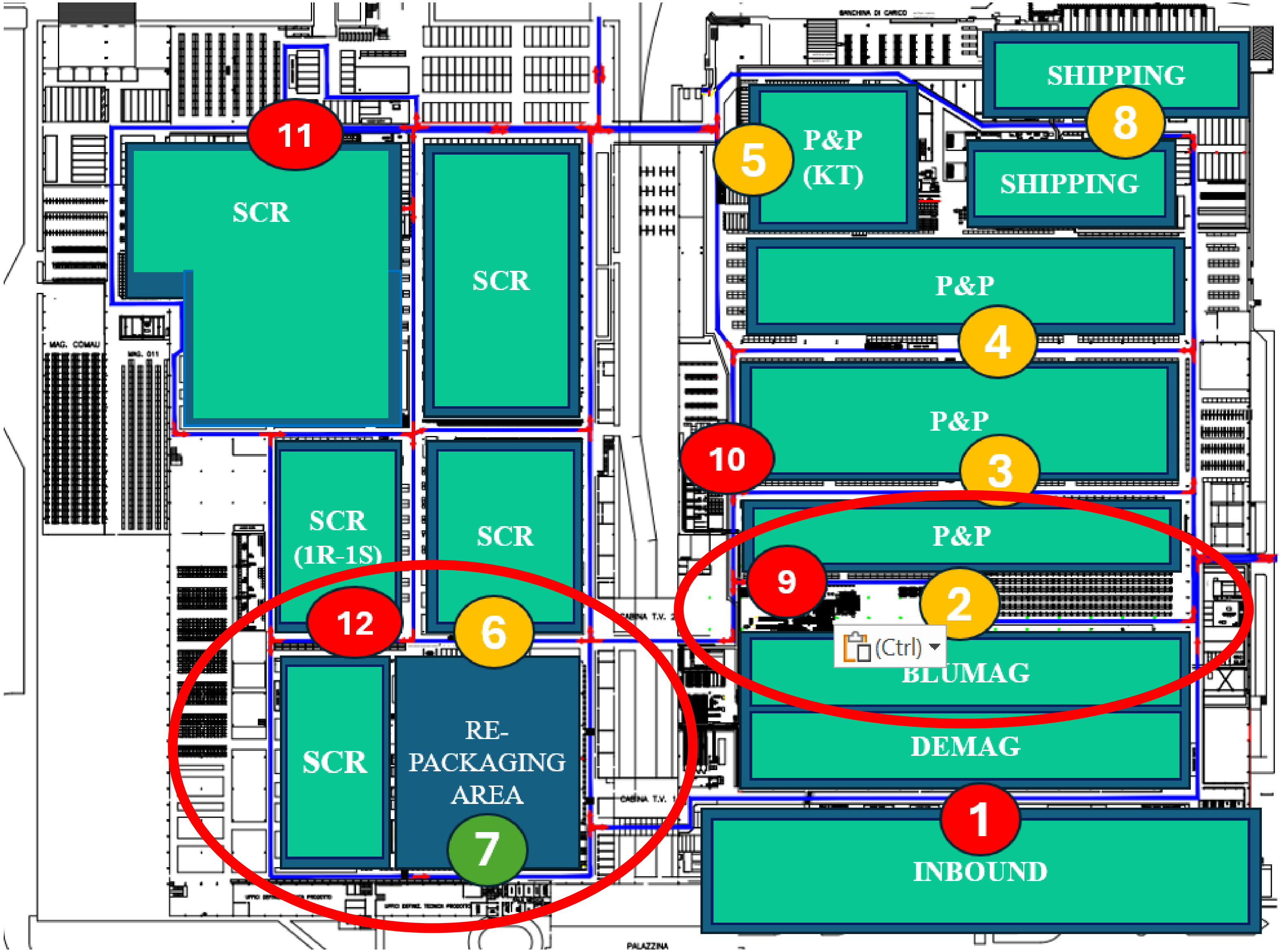

Figure 34: Internal Routes Layout AS-IS

Given the structural and layout constraints of the warehouse, as well as the need to maintain consistency across all routes, several trials were carried out to identify the most suitable solution capable of meeting these constraints while optimizing overall travel paths.

Two alternative hypotheses were developed (referred to as **TO-BE Hp1** and **TO-BE Hp2**), each introducing different modifications to the internal circulation routes of the warehouse. The main difference between the two solutions lies in the configuration of the routes: while **TO-BE Hp1** follows a specific circulation pattern, turning in one direction at key intersections, TO-BE Hp2 adopts an alternative pathing logic, where the same intersections are approached in a different direction.
Both configurations were designed and validated through a combination of theoretical simulations and practical on-site tests, in order to determine the optimal combination of routes while taking into account layout constraints and possible interferences with other material flows.
A comparative analysis was then performed to assess the effectiveness of these alternatives.

The tables below present the comparison of the Distances Traveled (expressed in meters) in the two proposed TO-BE scenarios against the current AS-IS situation. In line with the measurement approach adopted for the Distance Traveled (D) KPI, the analysis was conducted by separately considering the Storage and Shipping flows, and by distinguishing between Full-Load and Empty-Load movements.

Origin Point	Destination Point	Frequency /route	Distance **AS IS** [mt]	Distance **TO-BE Hp1** [mt]	Distance **TO-BE Hp2** [mt]
INBOUND	KT	1	456	760	482
INBOUND	P&P 10	3	519	368	259
INBOUND	REPACKAGING AREA	21	854	228	547
INBOUND	SCR-PUTAWAY	23	600	465	440
INBOUND	SHIPPING	3	676	694	658
INBOUND	P&P 80	13	305	467	338
INBOUND	BLUMAG-PUTAWAY	5	552	368	259
REPACKAGING AREA	BLUMAG-PUTAWAY	6	803	442	775
REPACKAGING AREA	P&P 10	3	772	442	775
REPACKAGING AREA	P&P 80	14	566	538	867

Table 28: Storage Flow – Route Distance: AS-IS vs TO-BE Scenarios for Full-load movements

Origin Point	Destination Point	Frequency /route	Distance AS IS [mt]	Distance **TO-BE Hp1** [mt]	Distance **TO-BE Hp2** [mt]
KT	INBOUND	2	798	480	610
P&P 10	INBOUND	4	1047	260	369
REPACKAGING AREA	INBOUND	13	258	709	529
SCR-PUTAWAY	INBOUND	23	495	445	349
SHIPPING	INBOUND	3	975	655	700
PP 80	INBOUND	18	808	335	466
BLUMAG-PUTAWAY	INBOUND	6	1114	260	369
BLUMAG-PUTAWAY	REPACKAGING AREA	3	852	495	276
P&P 10	REPACKAGING AREA	2	783	495	276
P&P 80	REPACKAGING AREA	8	538	565	377

Table 29: Storage Flow – Route Distance: AS-IS vs TO-BE Scenarios for Empty-load movements

Origin Point	Destination Point	Frequency /route	Distance AS IS [mt]	Distance **TO-BE Hp1** [mt]	Distance **TO-BE Hp2** [mt]
DEMAG	SHIPPING	9	514	339	280
BLUMAG-PACKING	SHIPPING	10	737	1022	478
SCR-PACKING	SHIPPING	29	337	555	337
1 R/1 S	SHIPPING	16	755	653	510

Table 30: Shipping Flow – Route Distance: AS-IS vs TO-BE Scenarios for Full-load movements

Origin Point	Destination Point	Frequency /route	Distance AS IS [mt]	Distance **TO-BE Hp1** [mt]	Distance **TO-BE Hp2** [mt]
SHIPPING	DEMAG	11	357	519	340
SHIPPING	BLUMAG-PACKING	11	359	475	256
SHIPPING	SCR-PACKING	27	570	342	570
SHIPPING	1 R/1 S	14	692	465	523

Table 31: Shipping Flow – Route Distance: AS-IS vs TO-BE Scenarios for Empty-load movements

As in the Measure phase, the distance for each individual route, reported in the fourth, fifth and sixth columns of the tables, was multiplied by its corresponding daily frequency (third column) of execution, in order to calculate the total kilometers traveled per day for each route. These values were then aggregated to determine the overall daily distance traveled, corresponding to the **Distance Traveled (D)** KPI. Subsequently, this total distance was converted into the daily time required for pure material transportation activities within the Turin warehouse, assuming an average Tugger Train speed of 7 km/h. The resulting value represents the **Theoretical Cycle Time (CT_{th})** associated exclusively with the pure movement of the Tugger Train from point X to point Y.

All calculations were performed for both improvement hypotheses, **TO-BE Hp1** and **TO-BE Hp2.**

The following graphs provide a visual comparison of the improvement scenarios **TO-BE Hp1** and **TO-BE Hp2** with respect to the current **AS-IS** situation. The analysis is presented by distinguishing between the **Storage Flow** and the **Shipping Flow**.

For both the flows the first set of charts (Figure 35 and 38) reports the comparison between scenarios, distinguishing **Full-Load** and **Empty-Load** movements in order to highlight the different levels of improvement achievable for each type of operation.
Subsequently, an aggregated chart is presented, where Full-Load and Empty-Load movements are combined to provide the total kilometers traveled per day for the Storage Flow (Figure 36) and for the Shipping Flow (Figure 39).
Finally, the overall daily distance traveled has been converted into hours per day, in order to calculate the Theoretical Cycle Time (CT_{th}), represented in Figure 37 for the Storage Flow and in Figure 40 for the Shipping Flow.

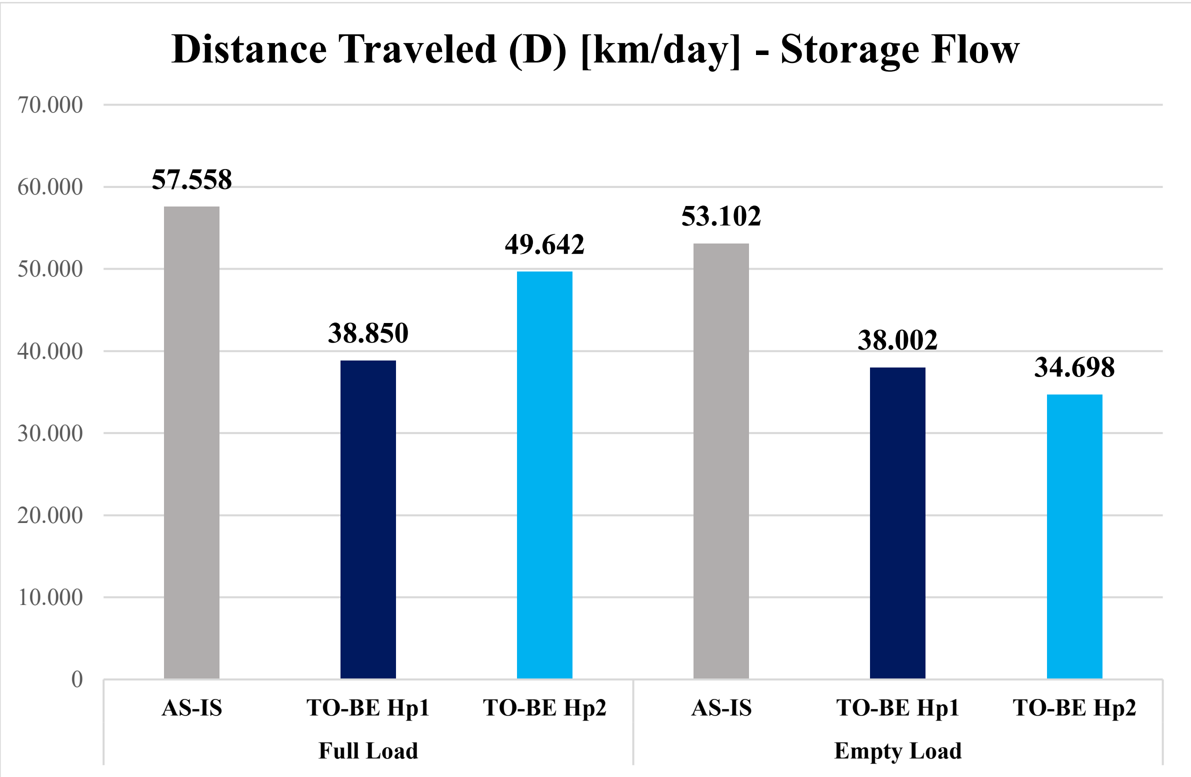

Figure 35: Storage Flow – Distance Traveled: AS-IS vs TO-BE Scenarios (Full/Empty Load)

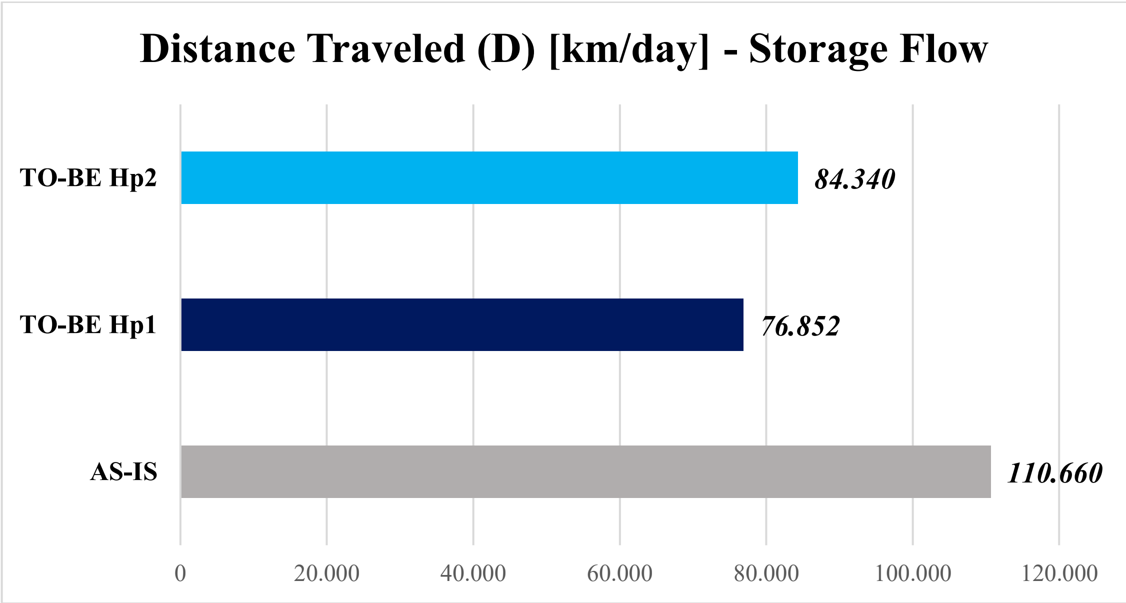

Figure 36: Storage Flow – Distance Traveled: AS-IS vs TO-BE Scenarios (Aggregated Full- and Empty-Load Movements)

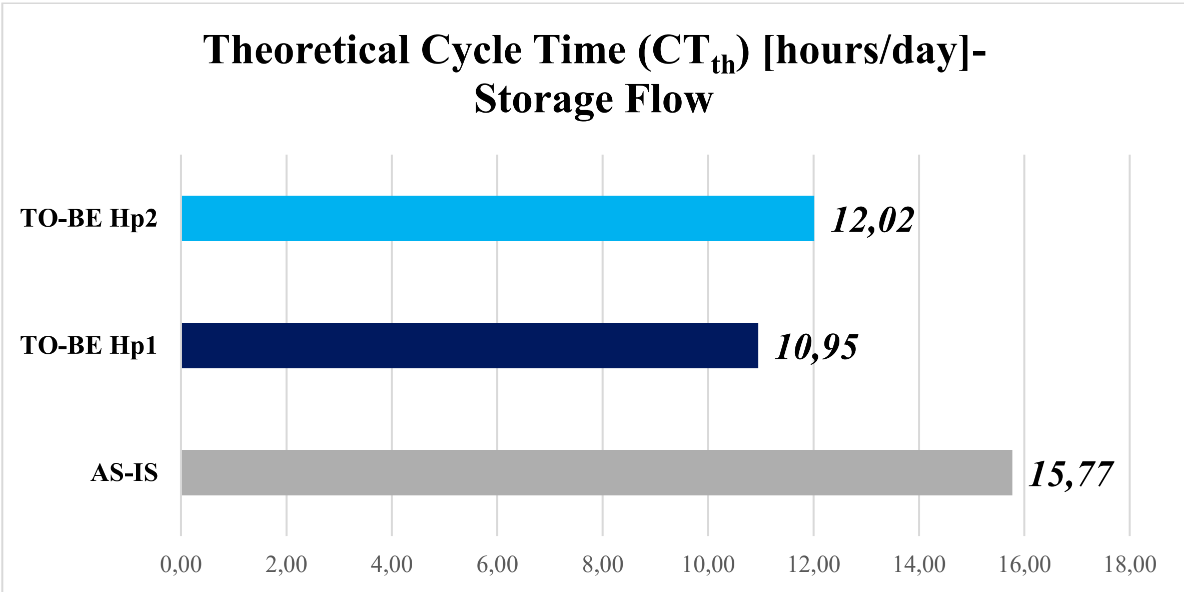

Figure 37: Storage Flow – Theoretical Cycle Time: AS-IS vs TO-BE Scenarios (Aggregated Full- and Empty-Load Movements)

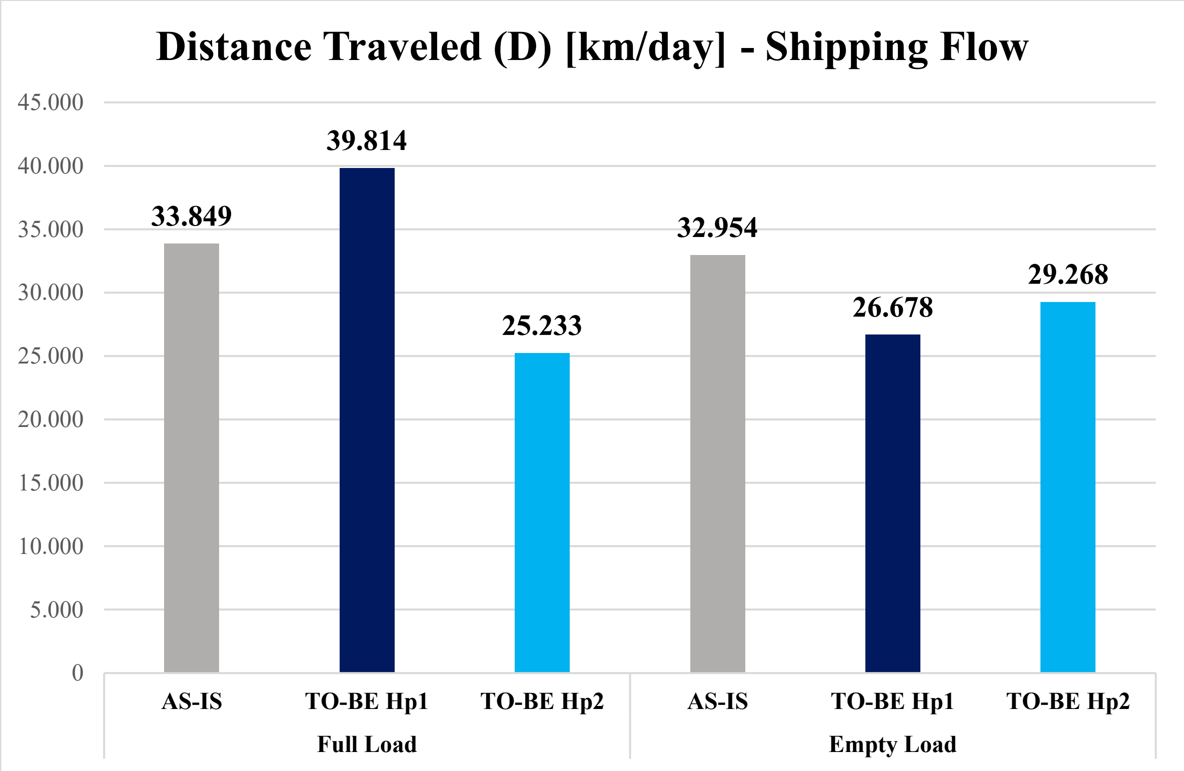

Figure 38: Shipping Flow – Distance Traveled: AS-IS vs TO-BE Scenarios (Full/Empty Load)

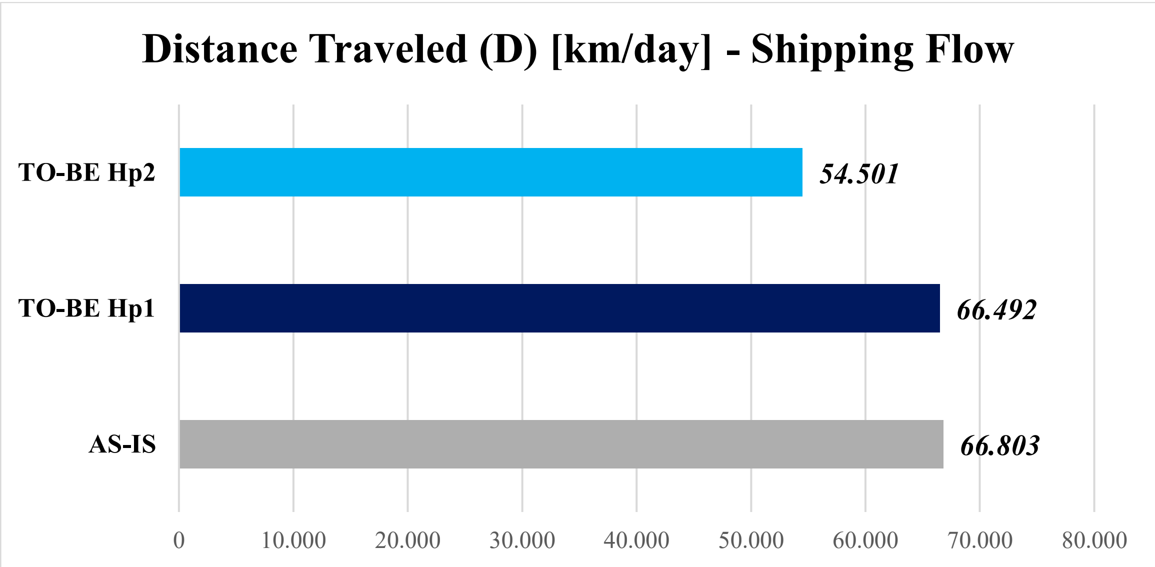

Figure 39: Shipping Flow – Distance Traveled: AS-IS vs TO-BE Scenarios (Aggregated Full- and Empty-Load Movements)

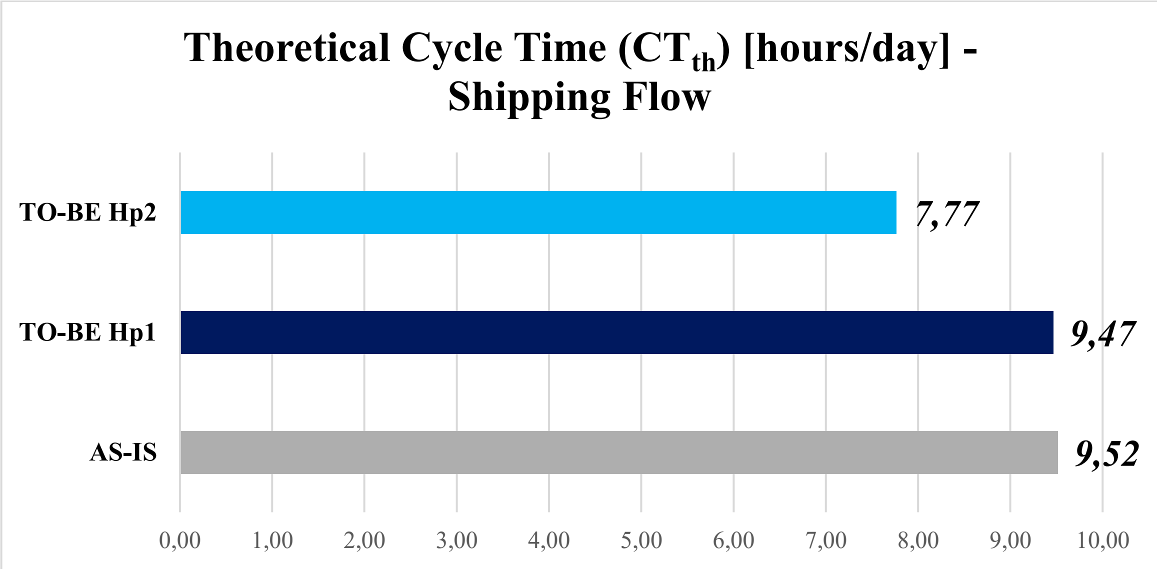

Figure 40: Shipping Flow – Theoretical Cycle Time: AS-IS vs TO-BE Scenarios (Aggregated Full- and Empty-Load Movements)

As illustrated in the graphs above, the analysis of the two redesign scenarios highlights the impact on both the **Storage Flow** and the **Shipping Flow** in terms of kilometers traveled per day and the corresponding theoretical cycle time.

For the first scenario (**TO-BE Hp1**), the results are as follows:

- **Storage Flow**: 76.8 km/day (Figure 36), including 38.8 km/day for Full-Load movements and 38.0 km/day for Empty-Load movements (Figure 35). These distances correspond to **10.95 hours/day** (Figure 37) of pure travel time for Tugger Train.
- **Shipping Flow**: 66.5 km/day (Figure 39), including 39.8 km/day for Full-Load movements and 26.7 km/day for Empty-Load movements (Figure 38), corresponding to **9.47 hours/day** (Figure 40).

For the second scenario (**TO-BE Hp2**), the results are as follows:

- **Storage Flow**: 84.3 km/day (Figure 36), including 49.6 km/day for Full-Load movements and 34.7 km/day for Empty-Load movements (Figure 35), corresponding to **12.02 hours/day** (Figure 37).
- **Shipping Flow**: 54.5 km/day (Figure 39), including 25.2 km/day for Full-Load movements and 29.2 km/day for Empty-Load movements (Figure 38), corresponding to **7.77 hours/day** (Figure 40).

The following tables summarize the improvements observed in each scenario compared to the current **AS-IS** condition.

With reference to the **Storage Flow**, scenario **TO-BE Hp1** leads to a reduction in the Distance Traveled (D), and consequently in the Theoretical Cycle Time (CT_{th}), of **33%** for Full-Load movements and **29%** for Empty-Load movements. Conversely, scenario **TO-BE Hp2** results in a reduction of **14%** for Full-Load movements and **35%** for Empty-Load movements.

Table 32 shows the data for both D and CT_{th}, with a comparison between the two proposed scenarios and the AS-IS situation for the Storage Flow.

		Distance Traveled (D) [km/day]	Theoretical Cycle Time [hours/day]	Improvement (%)
AS-IS	Full-Load	57.6	8,20	/
	Empty-Load	53.1	7,57	
TO-BE Hp1	Full-Load	38.8	5,53	-33%
	Empty-Load	38.0	5,40	-29%
TO-BE Hp2	Full-Load	49.6	7,07	-14%
	Empty-Load	34.7	4,93	-35%

Table 32: Improvement Results (%) for Storage Flow: comparison between TO-BE Scenarios (Full vs Empty Loads)

When aggregating the results (combining both Full-Load and Empty-Load movements), the total improvement that can be achieved is **31%** with scenario TO-BE Hp1 and **24%** with scenario TO-BE Hp2 (see Table 33).

	AS-IS	TO-BE Hp1	TO-BE Hp2
Distance Traveled (D) [km/day]	110,6	76,8	84,3
Theoretical Cycle Time [Time/day]	15:46:57	10:57:23	12:01:25
Hours/day/D	15,77	10,95	12,02
Theoretical Cycle Time [hours/day]	/	**-31%**	**-24%**

Table 33: Improvement Results (%) for Storage Flow: comparison between TO-BE Scenarios

Regarding the **Shipping Flow**, scenario **TO-BE Hp1** generates mixed results, with a deterioration of **18%** for Full-Load movements compared to the AS-IS baseline, but an improvement of **19%** for Empty-Load movements. In contrast, scenario **TO-BE Hp2** delivers consistent benefits across both movement types, with a reduction of **26%** for Full-Load movements and **11%** for Empty-Load movements.

Table 34 reports the results described above:

		Distance Traveled (D) [km/day]	Theoretical Cycle Time [hours/day]	Improvement (%)
AS-IS	Full-Load	33,8	4,82	/
	Empty-Load	32,9	4,68	
TO-BE Hp1	Full-Load	39,8	5,67	18%
	Empty-Load	26,7	3,80	-19%
TO-BE Hp2	Full-Load	25,2	3,58	-26%
	Empty-Load	29,2	4,17	-11%

Table 34: Improvement Results (%) for Shipping Flow: comparison between TO-BE Scenarios (Full vs Empty Loads)

When aggregated, the overall result for the Shipping Flow corresponds to a marginal improvement of **1%** under scenario TO-BE Hp1 and a more significant improvement of **18%** under scenario TO-BE Hp2 (see Table 35).

	AS-IS	TO-BE Hp1	TO-BE Hp2
Distance Traveled (D) [km/day]	66,8	66,5	54,5
Theoretical Cycle Time [Time/day]	09:31:49	09:28:42	7:46:13
Theoretical Cycle Time [hours/day]	9,52	9,47	7,77
Improvement (%)	/	**-1%**	**-18%**

Table 35 Improvement Results (%) for Shipping Flow: comparison between TO-BE Scenarios

Considering the interactions between the Storage and Shipping flows and their combined effects on overall performance improvement, the solution selected for implementation was **TO-BE Hp2**.

This scenario demonstrated the most balanced trade-off between feasibility and efficiency, resulting in an overall **21% reduction in the Distance Traveled (D) KPI** and **Theoretical Cycle Time (CT_{th})**. This improvement is calculated as the average between the improvement results for both the Storage Flow and the Shipping Flow, corresponding to a **24%** for the Storage Flow and an **18%** for the Shipping Flow.

This improvement also had a measurable impact on the KPI **Cycle Time (CT),** that represents the real cycle time, which was assessed during the *Control and Monitoring phase* (chapter 10).

The monitoring activity was carried out after the **go-live** of the specific solution concerning the redesign of internal routes, which took place on **July 21, 2025,** and extended over a period of two weeks. The evaluation of the real impact of the routes redesign on the process performance was made possible by the data collected during this phase, which gave a realistic measurement of the cycle time (CT) under real operating conditions.

The expected impact on the **Cycle Time (CT)** can also be estimated in advance by considering the improvements achieved on the **Theoretical Cycle Time (CT_{th})**. The real cycle time is unavoidably impacted by operational variability, such as variations in driving speed and unexpected disruptions along the routes. For this reason, the improvement measured on the real CT is expected to be slightly lower than that estimated theoretically.

By assuming an intrinsic process inefficiency of approximately 10%, it is possible to estimate a realistic improvement of the CT of around **21%** for the **Storage Flow** and **16%** for the **Shipping Flow**, leading to an overall estimated improvement of **19%.** These estimations will then be validated during the *Monitoring phase*, in which the KPI will be recalculated based on actual operating data, thus allowing the assessment of the effective impact of the route redesign on the overall process performance.

9.2. Introduction of Hook/Unhook configuration

In parallel with the analysis and implementation of the route redesign solution, the project team also examined an additional solution, defined as solution (2) in the FMEA analysis, aimed at reducing the waiting time associated with loading and unloading activities at the stations. This waiting time, defined as $T_{u/l}$ and evaluated during the *Measure phase*, is categorized as Non-Value-Added (NVA) and represent a significant inefficiency within the process.

As highlighted in the root cause analysis (Chapter 8.1), the main causes contributing to this inefficiency are:

- Lack of availability of an empty wagon at the station
- Lack of availability of a free parking slot within the area
- Lack of availability of a forklift operator to carry out the material loading/unloading activity

All these issues are intrinsically linked to the same limitation: the Tugger Train driver, in several stations across the warehouse, does not always have the possibility to perform the immediate full/empty wagon exchange upon arrival. Internally, this operation is defined as *"hook/unhook"* (hereafter this term will be used to refer to the proposed solution within the project).

The proposed solution specifically involves the implementation of *hook/unhook system* at origin and destination points in the Tugger Trains flow within the Turin warehouse. The concept of *hook/unhook* concretely consists in the introduction of a double-parking configuration at each station, ensuring the constant availability of at least one stationary wagon to allow the Tugger Train driver to perform a direct full/empty exchange. This eliminates the need to wait for the completion of material loading or unloading operations before resuming the route, thereby reducing idle times and improving overall process performance.

More specifically, the practical function of a *hook/unhook* station differs slightly depending on whether the station is classified as an origin or a destination point.

<u>Origin Stations</u>

Origin stations include areas where material is initially loaded onto the Tugger Train for subsequent handling, as described in paragraph 6.3.

In these stations, the availability of a double-parking system enables the Tugger Train driver, upon completing an empty-load movement, to immediately park the empty wagon in the free slot and immediately hook a full wagon—previously loaded with material—located in the adjacent slot. This mechanism ensures that a wagon is always available for loading operations, eliminating the driver's waiting time associated with wagon loading activities ($T_{u/l}$).

Destination Stations

Destination stations are defined as all areas where the transported material must be unloaded for further processing, as described in section 6.3.

In these stations, the hook/unhook configuration allows the Tugger Train driver, upon completing a full-load movement, to immediately park the full wagon in the designated slot and simultaneously attach an empty wagon—previously unloaded during the preceding cycle—from the adjacent slot. This enables the driver to promptly resume operations by initiating an empty-load movement back toward the origin station.

This approach eliminates the need for Tugger Train drivers waiting during the direct unloading activity performed by forklift operators before the material handling process can continue, significantly reducing Non-Value-Added activities.

The analysis supporting the implementation of this solution was carried out by examining all origin and destination stations, distinguishing between those already equipped with the hook/unhook configuration and those where this configuration was not present.

Stations already provided with the hook/unhook system are the following:

- **Storage Flow**: INBOUND, P&P 80, P&P 10
- **Shipping Flow**: BLUMAG-PACKING, DEMAG, SCR-PACKING

Stations not equipped with the hook/unhook configuration are the following:

- **Storage Flow**: SCR-PUTAWAY, BLUMAG-PUTAWAY, REPACKAGING AREA, KT
- **Shipping Flow**: 1R/1S, SHIPPING

By analyzing the waiting times at each station, used for the calculation of the variable $T_{u/}l$, it was observed that, for stations without the hook/unhook configuration, the average waiting time for loading/unloading operations exceeds 6 minutes. Conversely, in stations already equipped with this configuration, the average waiting time is equal to or below 5 minutes. Table 36 and 37 report the results of these measurements, highlighting the impact of direct loading/unloading (due to the absence of hook/unhook) for both the Storage and Shipping flows. Specifically, the data presented focus on **full-load movements** of the Storage Flow and **empty-load movements** of the Shipping Flow, as these routes most clearly demonstrate the differences in average waiting times.

Origin	Destination	Daily Frequency Movements/day	Average Loading/Unloading Time Movement/Route/day [min]
INBOUND	BLUMAG-PUTAWAY	4	7,6
INBOUND	REPACKAGING AREA	19	18,8
INBOUND	KT	1	8,3
INBOUND	P&P 10	3	4,4
INBOUND	P&P 80	13	2,7
INBOUND	SCR-PUTAWAY	23	8,7
INBOUND	SHIPPING	3	8,4

Table 36: Loading/Unloading Time for Storage Flow

Origin	Destination	Daily Frequency Movements/day	Average Loading/Unloading Time Movement/Route/day [min]
SHIPPING	1 R/1 S	14	12,2
SHIPPING	BLUMAG-PACKING	11	2,5
SHIPPING	DEMAG	10	2,1
SHIPPING	SCR-PACKING	27	4,7

Table 37: Loading/Unloading Time for Shipping Flow

From the data reported in the tables, it can be observed that stations lacking the hook/unhook configuration, such as BLUMAG-PUTAWAY, REPACKAGING AREA, and 1R/1S, present higher average waiting times for loading/unloading operations compared to stations already equipped with the configuration, such as BLUMAG-PACKING, DEMAG, and P&P 80.

In addition to this first observation, another relevant aspect emerges: waiting times at stations without hook/unhook are significantly more variable. This variability is influenced by several operational factors, including the availability of a forklift operator at the time of arrival, as well as the quantity and type of material to be loaded or unloaded. For example, larger items and/or standardized units, such as euro pallets, can be handled more quickly and easily, whereas smaller items or materials with non-standard dimensions require longer and more complex loading/unloading operations, thereby increasing waiting times.

The time-series plots reported below illustrate this difference by comparing the behavior and distribution of waiting time measurements for stations with and without the hook/unhook configuration. Specifically, Figure 41 reports the results for **SCR – PUTAWAY**, as an example of a station not equipped with hook/unhook, while Figure 42 presents the case of

SCR – PACKING, which was already equipped with the configuration. The comparison clearly highlights not only the higher average waiting time but also the greater dispersion and variability of the measurements in stations without hook/unhook.

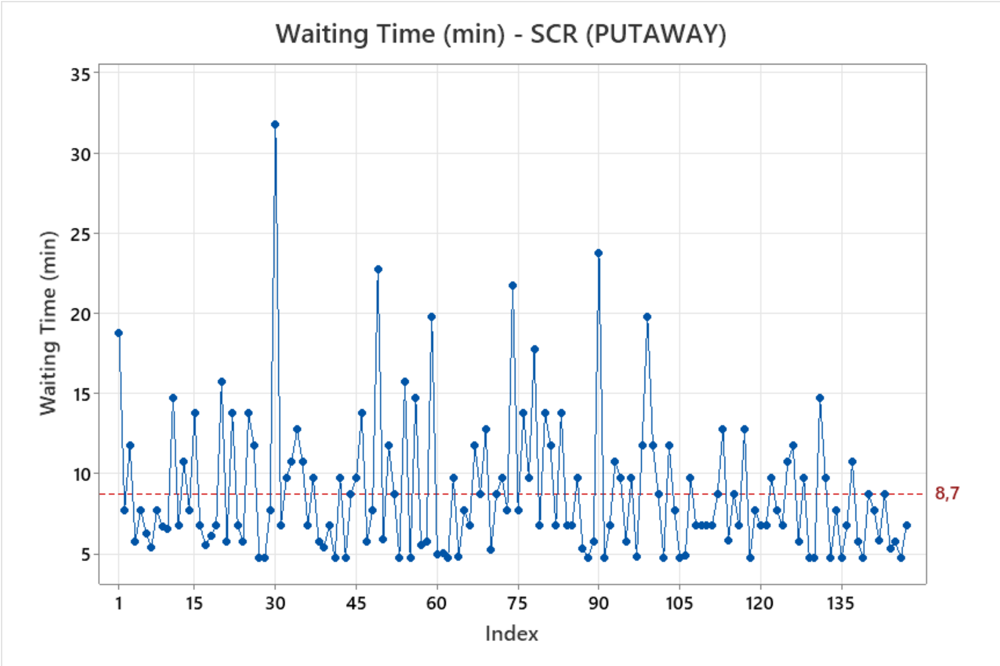

Figure 41: Time Series Plot – Waiting Time – SCR-PUTAWAY

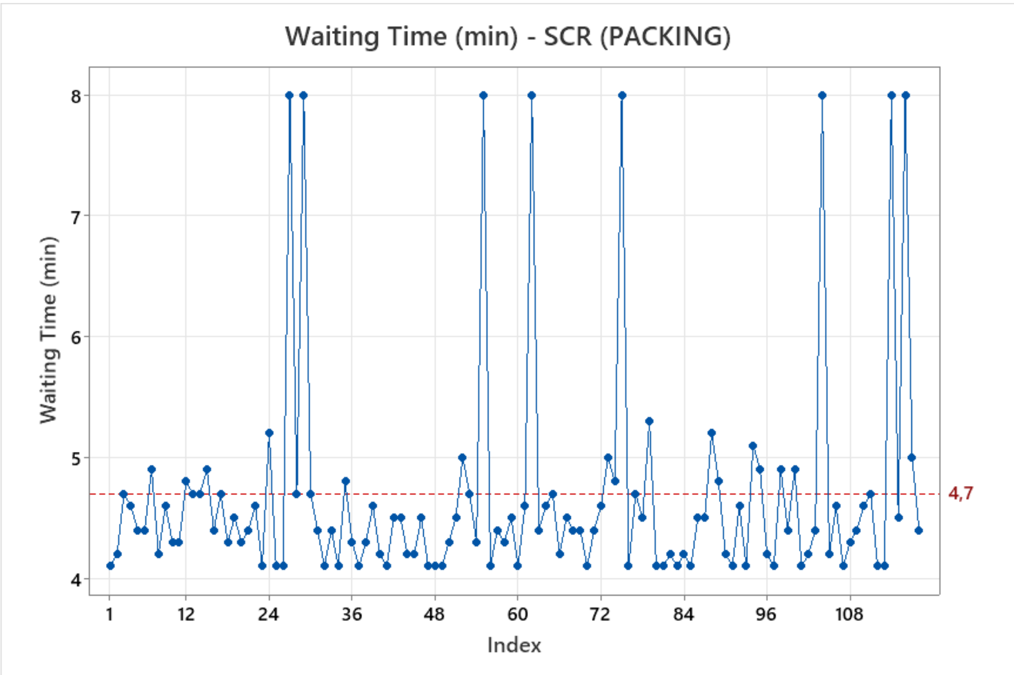

Figure 42: Time Series Plot – Waiting Time – SCR-PACKING

Following these considerations and the analysis of the time-series plots reported above, it is useful to further investigate the variability of the measurements by examining their statistical distributions. In particular, the use of a **box plot** (Figure 43) provides a more rigorous comparison between stations equipped with the hook/unhook configuration and those without it, allowing to directly compare the variance and dispersion of waiting times across the two cases.

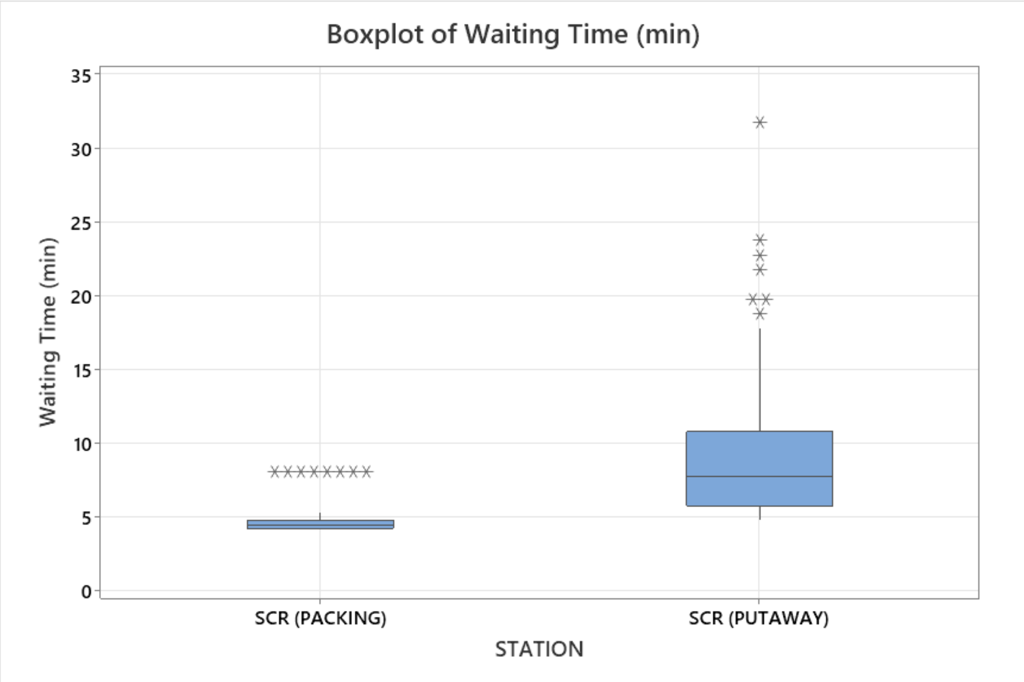

Figure 43: Box Plot – Comparison between Waiting Time SCR PUTAWAY-PACKAGING stations

From the box plot analysis, it can be observed that the station equipped with the hook/unhook configuration (SCR – PACKING) presents a distribution of loading/unloading times ($T_{u/l}$) that is less variable compared to the station without this configuration (SCR – PUTAWAY). This difference in variability is visually evident from the relative width of the boxes in the plot, which indicate a narrower spread of data when the hook/unhook system is in place.

It is also important to consider the presence of outliers within the two distributions. In the case of SCR – PACKING, the outliers can be attributed to specific *special causes*, such as situations where the designated parking space was temporarily occupied by material, or when the previous Tugger Train was still present in the station, preventing immediate execution of the hook/unhook operation. Since these occurrences are exceptional events not representative of the normal process, they can reasonably be excluded from the statistical evaluation of the distribution. Nevertheless, even when considering these eight outliers, the

overall variability of the SCR – PACKING distribution remains significantly lower than that observed in SCR – PUTAWAY.
On the other hand, the outliers in the SCR – PUTAWAY distribution cannot be considered as arising from special causes. Rather, they may simply reflect longer loading/unloading times associated with ordinary variability factors already discussed, such as the availability of a forklift operator or the type and size of the handled material (e.g., non-standard dimensions requiring more complex handling). For this reason, these values cannot be discarded and must continue to be included in the analysis of the distribution.

Finally, to complement these graphical observations, the detailed statistical results are reported in the Graphical Summaries (Figures 44 and 45). Specifically, the SCR – PACKING distribution shows a mean waiting time of **4.7 minutes** with a standard deviation of **0.94 minutes**, confirming its reduced variability and lower average compared to SCR – PUTAWAY, which instead reports a mean waiting time of **8.84 minutes** with a standard deviation of **4.37 minutes**.

These results highlight that the project of extending hook/unhook stations across the warehouse therefore pursues a dual objective:

- reducing the average waiting time caused by loading/unloading operation ($T_{u/l}$),
- reducing variability, establishing a stable and standard process for the internal material handling flow.

In particular, the reduction of the average $T_{u/l}$ also contributes to lowering the overall process time (PT), improving Tugger Train Efficiency (E), and ultimately enhancing the overall performance of the material handling process.

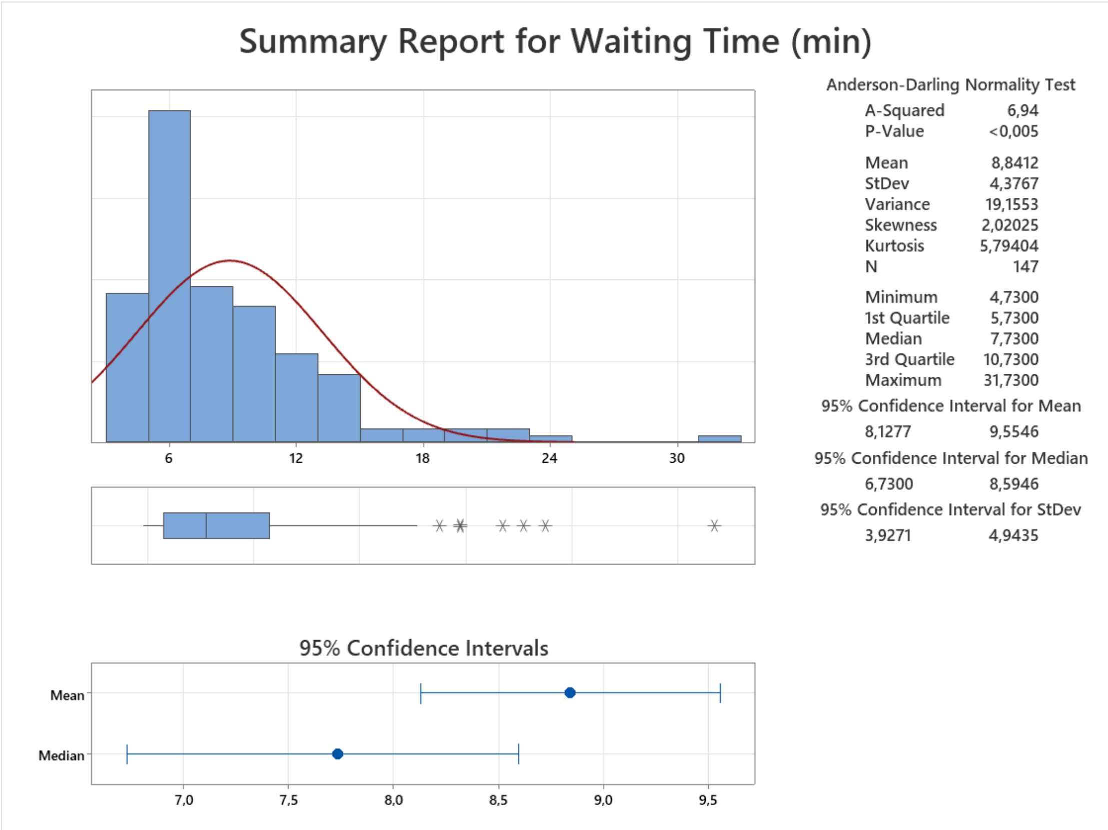

Figure 44: Graphical Summary SCR (PUTAWAY) – Waiting Time Data Distribution

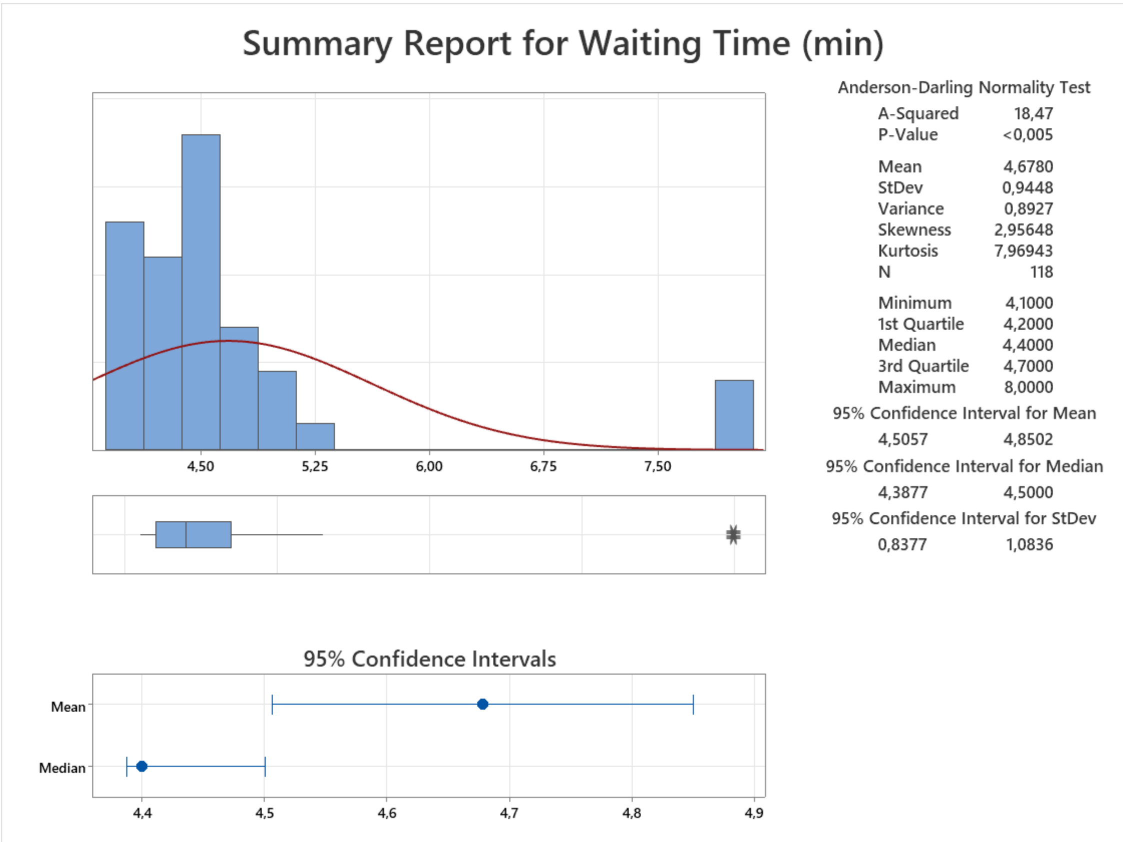

Figure 45: Graphical Summary SCR (PACKING) – Waiting Time Data Distribution

Following this additional process analysis, the implementation of the proposed solution was concretely developed through a detailed assessment of the stations where the hook/unhook system was not yet available. This evaluation included a review of the warehouse layout, analyzing both the available space and the feasibility of potential rearrangements or reconfigurations of the areas.
As a result of this study, the project team confirmed the feasibility of introducing the hook/unhook system in all missing stations, with the sole exception of the KT area. In this specific case, structural and spatial constraints did not allow the installation of the double-parking configuration. Nevertheless, this limitation has a negligible impact on the overall performance, since the KT station records a very low daily handling frequency: on average only one movement per day within the Storage Flow, and no movements for the Shipping Flow.
The following stations were therefore selected for the implementation of the hook/unhook system and will be subject to the subsequent performance evaluation in terms of waiting time reduction in terms of average and variability.

- SCR (PUTAWAY)
- BLUMAG (PUTAWAY)
- 1R/1S
- CONAS
- SHIPPING

The go-live of this solution took place on **July 21st, 2025**, simultaneously with the implementation of the previous solution concerning the redesign of internal routes.

9.3. AMR Implementation for Continuous Flow

The analysis of this solution has been conducted primarily through a qualitative rather than a quantitative approach, as its implementation had not yet taken place at the time of writing this thesis. Consequently, the Improve phase related to this solution focuses on the study of the current process and the definition of the TO-BE process, including layout modifications and identified process logics. However, the actual impact on KPIs could not be measured within the monitoring and control phase; instead, only expected and estimated results are presented.
This solution, reported with number (3) in the FMEA (Table 27, section 8.2) concerns the implementation of a dedicated flow managed by **Autonomous Mobile Robots (AMRs)**, displayed in the Figure 46 below.

Figure 46: AMR – Autonomous Mobile Robot

An Autonomous Mobile Robot (AMR) is a robotic system principally used for material handling acitivties in warehouses and industrial facilities. These robots are able to navigate within the environment, using sensors and artificial intelligence to map, localize and detect possible obstacles in complete autonomy. These robots are able to dinamically adapt and optimize their routes in real time when changing in the envionment occurs.

Given the characteristics of the flow under analysis, AMRs have been identified as the most suitable solution. This approach addresses one of the most critical inefficiencies identified in the Shipping Flow, represented by the lack of precision in the internal deliveries from the outflow areas to the Shipping department, where items are sorted and prepared for final delivery to the customer. As highlighted in the Measure phase of the project, this lack of accuracy generates significant inefficiency due to the additional time required by forklift operators to search for missing packages within the warehouse before completing the truck loading activities.

This inefficiency was quantified using two Key Performance Indicators (KPIs): (i) the **Delivery Inaccuracy Rate (DIR)**, which measures the share of delayed internal deliveries, and (ii) the

searching time, which quantifies the time spent by operators locating missing items. The corresponding results, reported in Section 7.3.3, demonstrate that 59% of internal deliveries to the Shipping department are delayed (**DIR = 59%**), generating a daily searching time of approximately **68 hours/day**, which accounts for **28%** of the total time spent on truck loading operations**.**

Root cause analysis conducted in the Analyze phase confirmed that these inefficiencies are caused by the absence of a continuous flow of material and by the lack of traceability of packaged items dispatched from the various outflow areas to the Shipping department.

To address these specific root causes, the project team proposed the introduction of **Autonomous Mobile Robots (AMRs)** together with a dedicated **management system for package traceability**. This integrated solution is designed to ensure a **continuous and fully traceable flow** of outbound material, thereby minimizing delays and inefficiencies in the Shipping process.
However, due to weight and volume constraints, AMRs can only handle materials that are relatively small and sufficiently lightweight. Hence, given the heterogeneity of the materials managed within the Turin warehouse, in terms of both weight and dimensions, the solution can be applied only to a selected portion of the Shipping Flow.
As outlined in the Define phase (specifically in section 6.2), the Shipping Flow can be segmented into two main categories, based on an ABC analysis combined with an assessment of item weight and volume (reported in the paragraph 4.2.4):

- **Small, lightweight, and high-turnover materials**: These items are mainly handled by the automated warehouses (DEMAG and BLUMAG) and sent to the Shipping department. The handling of this flow is characterized by high frequency, fast picking operations, and limited weight and volume of the packed materials.
- **All other materials**: This category includes goods coming from the remaining warehouse zones. Their handling is typically marked by lower picking frequency and/or larger, heavier packaging units.

In the Measure phase, these two flows were originally considered together, since under the current **AS-IS configuration** all types of goods, regardless of size or weight, are handled and transported in the same manner by the Tugger Trains. However, for the purpose of designing, analyzing, and implementing the specific AMR-based solution, it was necessary to separate the flows. In fact, this solution is scoped exclusively for the flow of **“small, lightweight, and high-**

turnover materials" described above, that refers to the category of material represented by *small boxes grouped into larger carton boxes.*

Hence, the scope of this analysis and implementation is focused on the **shipping flow of small boxes originating from the BLUMAG and DEMAG** automated warehouses, as these represent the most suitable case for the deployment of Autonomous Mobile Robots in the Kuehne-Nagel Turin Warehouse.

Specifically, the implementation study for this solution is structured into several steps:

1. **Current process analysis and description**, including identification of actual layout of loading/unloading points, and handling process;
2. **Layout assessment**, considering the TO-BE configurations, the positioning of loading/unloading stations and handling route;
3. **Volume analysis and mission trigger logic**, to define AMR mission activation rules and prioritization in line with workload fluctuations and shipment deadlines;
4. **Definition of TO-BE flow**, describing the process TO-BE with the integration of the AMRs, with a summary explanation of the specific solution studied and the expected results.

The following paragraphs provide a detailed description of each of these implementation and analysis stages, outlining the methodology adopted and the expected impact on process efficiency.

9.3.1. Current Process flow

To initiate the study for the implementation of the AMR solution, the project team first analyzed in detail the specific flow selected for automation, namely the "small, lightweight, and high-turnover materials" flow, in its current AS-IS configuration.

This flow originates from the outflow zones of the automated warehouses BLUMAG and DEMAG, which handle different types of packaging, as described in Section 4.2.3.2. These include *small boxes grouped into larger carton boxes, pallets, and single large boxes*. The implementation of the AMR solution, together with the related design and feasibility analysis, focuses exclusively on the first category.

This type of material is managed in dedicated packaging bays of the two automated warehouses, illustrated in Figure 47, and structured as follows:

- **Zone A** → Generic DEMAG packaging bays, where different types of packages are processed, including small boxes and large single boxes;
- **Zone B** → Dedicated packaging bay for small boxes, specifically single-line orders, from the BLUMAG warehouse;
- **Zone C** → Dedicated packaging bay for small boxes, specifically single-line orders, from the DEMAG warehouse.

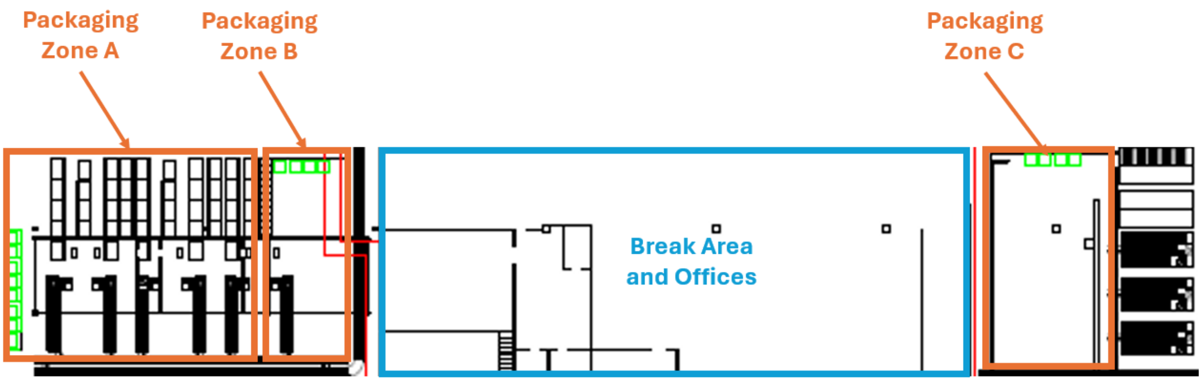

Figure 47: Layout of Packaging Areas - BLUMAG and DEMAG

From these packaging bays, small boxes are packed, labeled, and consolidated into larger carton boxes (as displayed in Figure 48). These carton boxes are then transported by forklift to a buffer area, located on the left side of Packaging Zone A. From this buffer, the consolidated boxes are loaded onto wagons and subsequently moved to the shipping department by Tugger Trains.

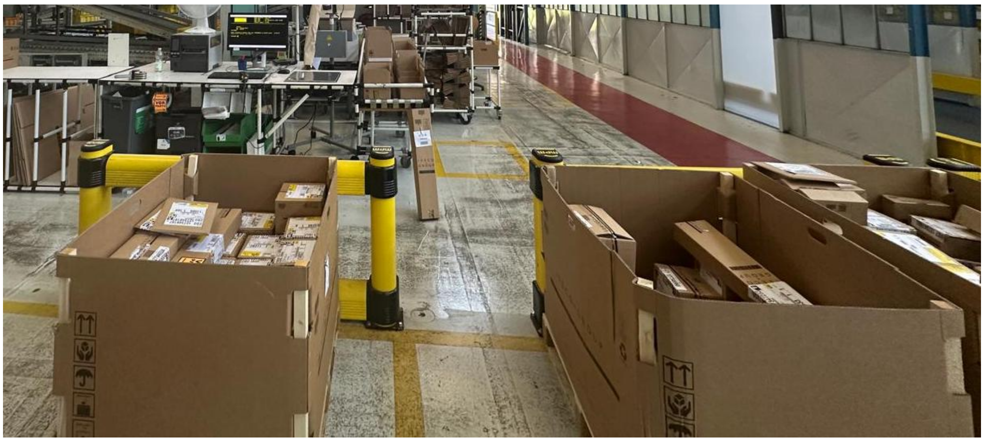

Figure 48: Small boxes grouped inside larger carton box

The grouping logic for consolidating small boxes into larger carton boxes is based on order type and packaging deadlines and/or shipment deadlines, depending on the distribution channel indicated on the shipping label (*cartellino collo*). A more detailed explanation of this logic will be provided in Section 9.3.3.

Once the carton boxes arrive at the Shipping Department, they are unloaded from the Tugger Train by a forklift operator and placed into a dedicated area, referred to as the **Macro UDR**. This area consists of:

- A **buffer area**, where carton boxes are stored temporarily before sorting the small boxes into their respective final containers. The final containers, once filled, are also deposited here before being loaded onto outbound trucks.
- A **sorting area**, where an operator, using a pallet truck, pick up the carton boxes from the buffer and manually sorts the small boxes into the final shipping containers. These containers are pre-positioned within the sorting area according to a predefined layout.

The layout of the **Macro UDR** in the Shipping Department is shown in Figure 49.

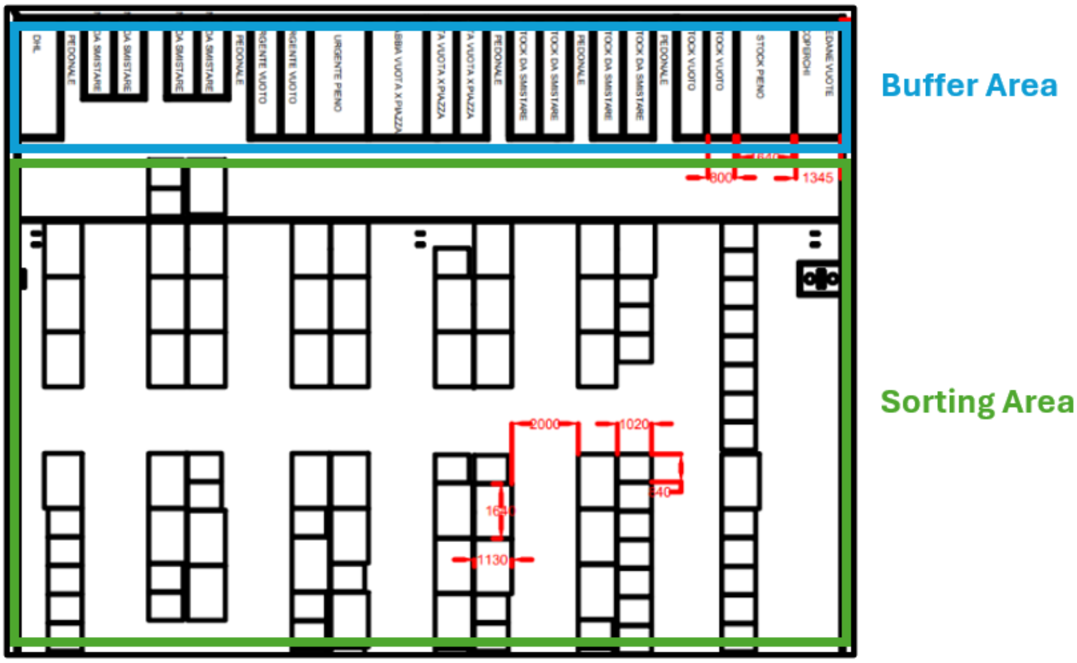

Figure 49: Macro UDR Layout AS-IS

To provide further clarity, a detailed flow chart of the current AS-IS process is presented in Figure 50, illustrating all the operational steps within this flow. This representation serves as the baseline for comparison with the redesigned TO-BE process following the implementation of AMRs.

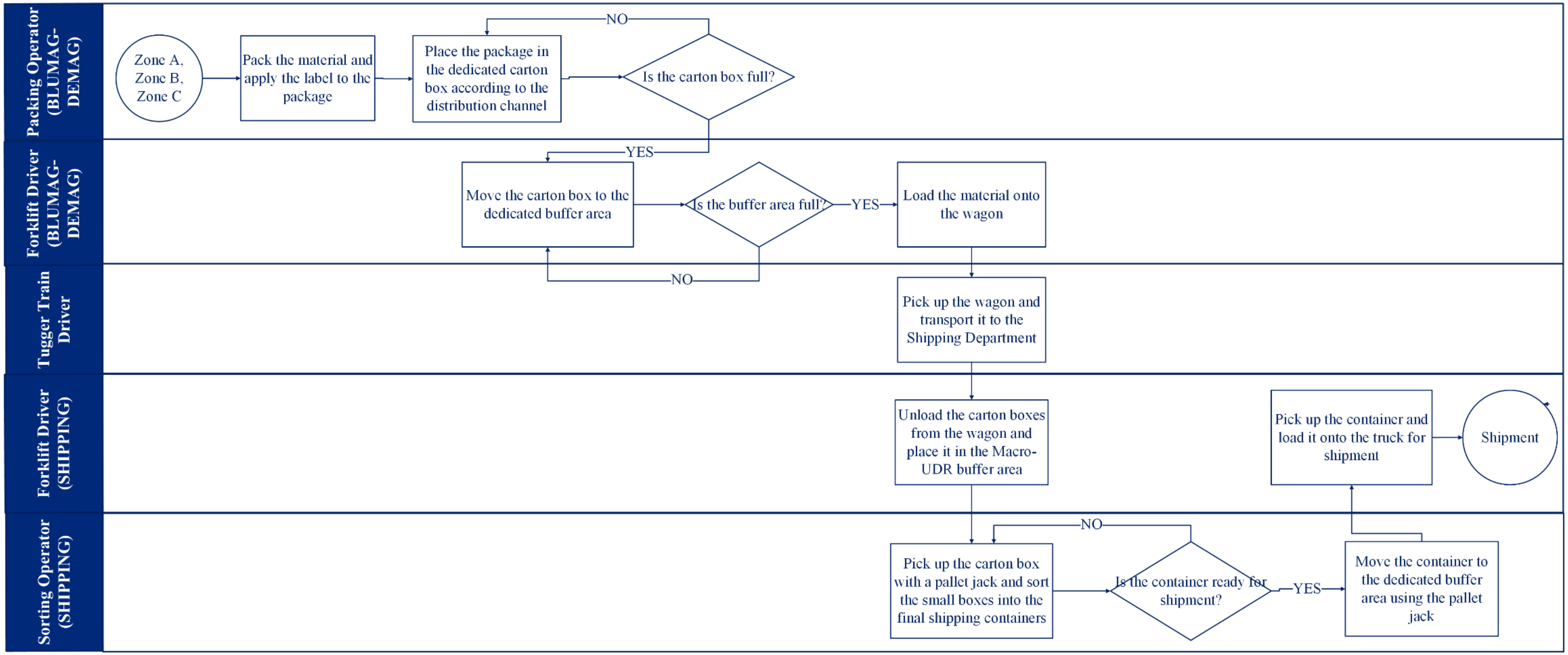

Figure 50: Flow Chart AS-IS Process - Packaging and Handling flow of small, lightweight and high turnover items BLUMAG and DEMAG

9.3.2. Layout Assessment

Following the AS-IS analysis of the flow and the warehouse layout, the project team studied the TO-BE configuration of the process with the introduction of two AMRs. This required an evaluation of several warehouse constraints, including spatial availability, layout limitations, and potential interferences with other handling flows.

In this section, the TO-BE layout is described, focusing specifically on the **loading stations, unloading stations, and the AMR route**, in line with the redesigned handling process and the new AMR operational logic.

Loading Stations

The *loading stations* are the points where packages from BLUMAG and DEMAG will be deposited for transport to the Shipping Department. In the TO-BE configuration, the carton boxes previously used for internal transportation will be replaced by wheeled trolleys, designed to be hooked and moved by AMRs. Figure 51 below illustrates the type of trolleys to be used.

Figure 51: Trolleys for small packages handling with AMR flow

During the layout design phase, it was necessary to consider that, due to interferences with other warehouse flows, AMRs will not have direct access to all packaging zones described in Figure 47. Specifically, AMRs will be able to access trolleys directly only in Packaging Zone A, while in Packaging Zones B and C direct access will not be possible.

Therefore, for the purposes of the TO-BE layout and process study, the packaging stations have been categorized into:

- **Direct-access loading stations (Packaging Zone A)** → These stations will be equipped with both trolleys and a digital device (tablets). The tablets will allow operators to scan the barcode on the trolley, containing shipment/packaging data, and activate an AMR mission through a specific management system. The AMR will then arrive at the station, pick up the full trolley, and simultaneously drop off an empty one retrieved from the unloading stations in the Shipping Department.
- **Indirect-access loading stations (Packaging Zones B and C)** → These stations will also be equipped with trolleys and tablets, but due to layout restrictions, AMRs will not reach them directly. Instead, packaging operators will manually move the prepared trolley from Zones B and C to the nearest direct-access station in Zone A, from where the AMR will take charge of the transport mission toward the Shipping Department.

A preliminary layout of the loading stations is shown in Figure 52, highlighting the distinction between direct and indirect access points.

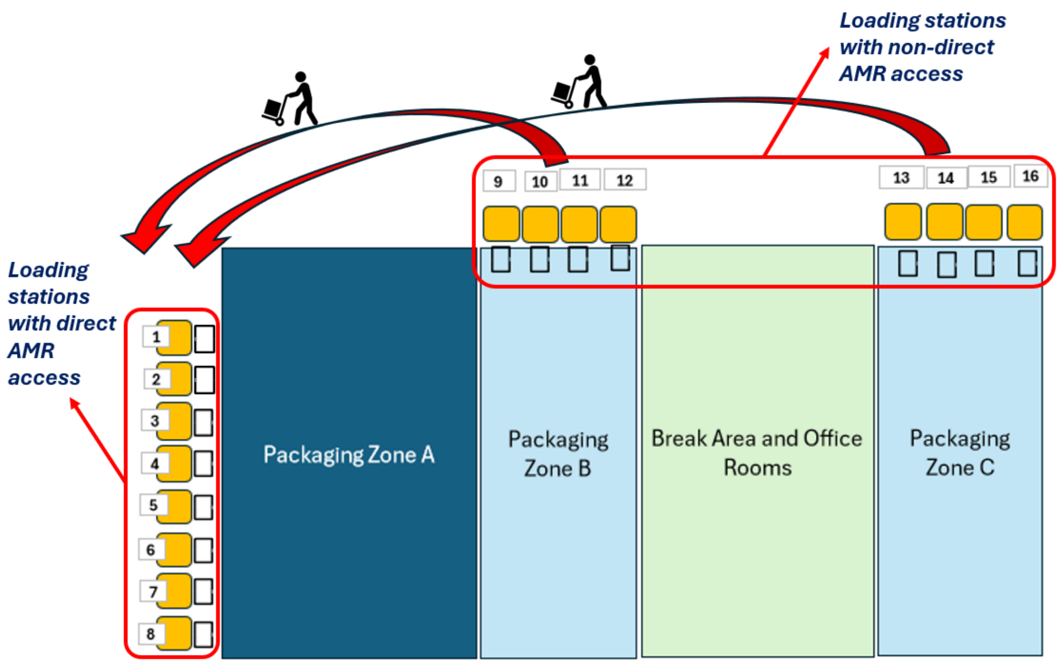

Figure 52 TO-BE Layout and Flow at AMR Loading Stations

As highlighted in the figure, **stations 1 to 8** are defined as **direct-access stations**, while **stations 9 to 16** correspond to **indirect-access stations**, requiring operator intervention to reposition the trolleys.

Once a transport mission is triggered (this process will be described in the following Section 9.3.3), AMRs will collect the full trolleys from the direct-access stations and deliver them to the dedicated **Macro UDR** area in the Shipping Department. Each loading station corresponds to a specific grouping, based on order type and shipment or packaging deadlines associated with the respective distribution channel.

Unloading Stations

The unloading stations are located within the Macro UDR area of the Shipping Department, where the AMRs will deliver the trolleys previously collected and transported from the BLUMAG and DEMAG loading stations.
These stations have been designed and positioned in a specific section of the Macro UDR, taking into account both spatial constraints and layout restrictions, and are organized as follows:

- **Full-trolleys unloading stations** → In these stations, the AMRs will deposit the carts loaded at the packaging zones. The carts will then be handled by the sorting operators, who will distribute the small packages into the final containers prepared for shipment.
- **Empty-trolleys unloading stations** → Once the sorting activity is completed, operators will place the empty carts in these stations. The AMRs, upon receiving a new transport mission, will collect the empty carts and return them to the loading stations, thereby creating a continuous closed-loop flow of full and empty carts.

The unloading stations have been placed on the side of the Macro UDR, diametrically opposite to the existing buffer area. This choice was made to align with the exit point of the AMR route and to minimize potential interferences with other material handling flows operating within the same area.

Figure 53 below illustrates a preliminary layout of the Macro UDR, showing the integration of the unloading stations.

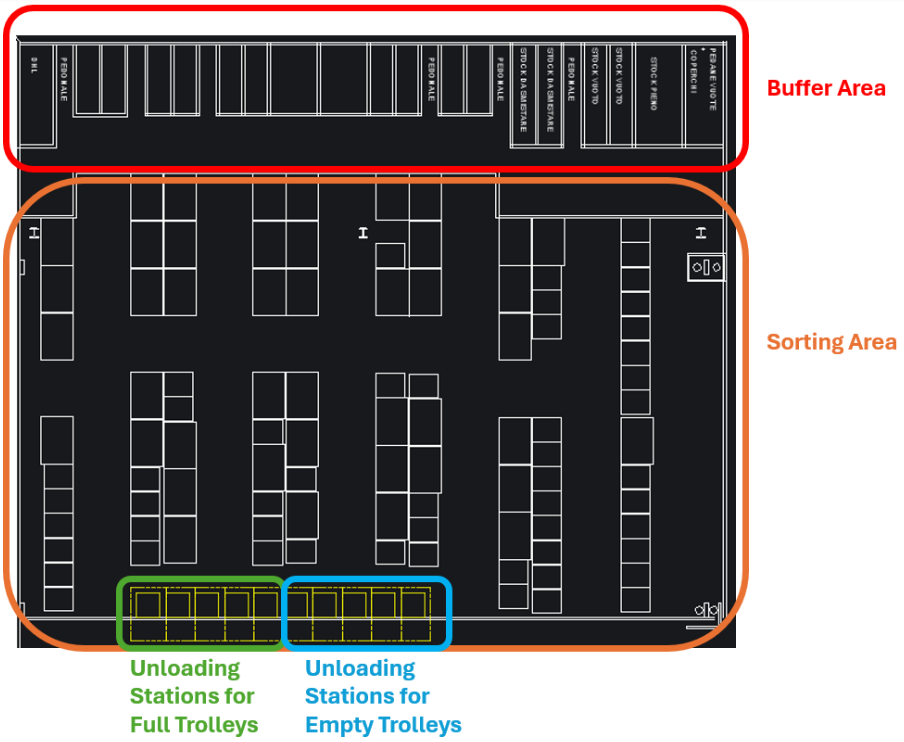

Figure 53: TO-BE Macro UDR Layout

As shown in the layout, the unloading stations are divided into **five** dedicated to **full trolleys** and **five** dedicated to **empty trolleys**. To integrate these stations within the available space of the Macro UDR, the pre-existing buffer area has been slightly reduced. This adjustment is justified by the fact that the flow of *small boxes grouped into larger carton boxes* originating from the BLUMAG and DEMAG automated warehouses represents approximately 60% of the total volume and therefore constitutes the largest share of this flow. Since this portion will no longer be transported via Tugger Trains and subsequently stored in the existing buffer area, but instead managed directly through the new AMR-based flow and redirected to the designated unloading stations, this buffer area can be reduced without compromising process performance.

AMR route

As part of the implementation study for the AMR-based solution, a **dedicated preferential route** was designed for the Autonomous Mobile Robots, taking into account warehouse layout constraints, available space, and potential interferences with other handling flows within the Kuehne-Nagel Turin warehouse. The defined route is illustrated in the layout provided in Figure 54 below. In the layout the **direct-access loading stations** (located in the DEMAG Packaging Area A) and the **unloading stations** within the Macro UDR are highlighted.

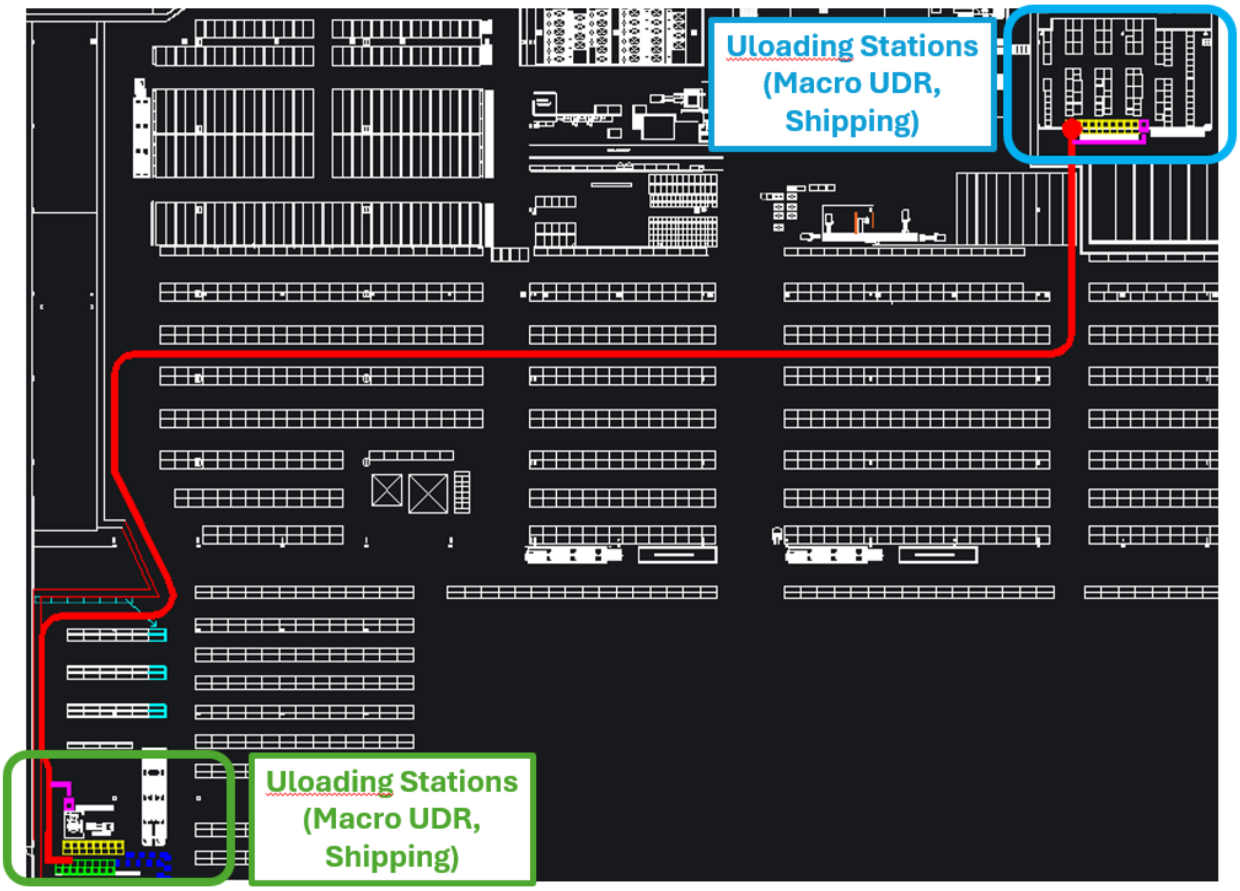

Figure 54: AMR preferential route

To provide a clearer understanding of the layout in terms of space and distances, it is important to note that the total length of the preferential route between the loading and unloading stations corresponds to approximately **550 meters**.

During the route design phase, particular attention was paid to identifying a configuration that would facilitate AMR access while ensuring that the path remained as **linear, short, and free from potential interferences** as possible. This route will be followed both in the outbound direction, when AMRs transport full trolleys from the loading stations to the unloading stations, and in the return direction, when AMRs bring empty trolleys back to the loading stations while initiating a new handling mission.

Although AMRs will normally operate along this predefined preferential path, which will be clearly marked within the warehouse through Visual Management systems, they are also capable of autonomously recalculating their route in case of anomalies, such as the presence of unexpected obstacles. This capability ensures operational continuity and prevents interruptions in the material handling process.

9.3.3. Volume Analysis and Mission Trigger Logic

Following the layout design, an analysis was conducted on handling volumes to establish the **logic for mission activation and prioritization** within the flow. This section reports the results of this analysis and presents a preliminary draft of the trigger configuration. It is important to note that this configuration will be further refined and validated during a testing phase planned for November 2025. Due to the project timeline, these results will not be included in the present study.

As already discussed in previous sections, each loading station is dedicated to a specific grouping of small packages, based on **order type** and on **packaging/shipping deadlines** associated with each distribution channel. This grouping logic, internally referred to as **"Pre-sorting"**, has been designed to facilitate and accelerate the outbound flow and subsequent sorting activities within the Macro UDR.

In the Kuehne-Nagel Turin warehouse, the final shipping logic is organized by **distribution channel**, that represent the final customer destination. Each channel is associated with a specific order type and deadline. Based on this classification, three macro-categories of orders type can be identified:

- **Urgent** → Channels with a very short lead time between packaging and final shipment. These orders require same-day dispatch and must be transported rapidly from outflow areas to the Shipping department;
- **Stock** → Channels with a longer lead time between packaging and shipment, for which immediate transportation to Shipping is not required;
- **Extra-Europe** → Channels with shipping destinations outside Europe, characterized by longer lead times similar to stock orders, but subject to dedicated downstream handling after sorting.

For the Stock and Extra-Europe categories (approximately 40% of total orders), no further subdivision is required, since no strict lead-time constraints apply.

Conversely, for the Urgent category (representing 60% of total orders), an additional breakdown by shipment and/or packaging deadlines is necessary. This results in the following four sub-categories:

- **Urgent Slot 1** → shipment/packaging deadlines between 12:00 and 17:30
- **Urgent Slot 2** → shipment/packaging deadlines between 17:30 and 19:30
- **Urgent Slot 3** → shipment/packaging deadlines between 19:30 and 23:30

○ **Urgent Slot 4** → shipment/packaging deadlines between 23:30 and 02:30 (next day)

Accordingly, each loading station of the packaging zones (A, B, and C) will be assigned to one of the following categories: Urgent Slot 1, Urgent Slot 2, Urgent Slot 3, Urgent Slot 4, Stock, or Extra-Europe.

The **priority logic** ensures that AMR missions are scheduled dynamically during the day according to the deadlines. For instance, at 16:00 the stations assigned to Urgent Slot 1 will have higher priority over those of Urgent Slot 2 or those of Stock, with AMR missions triggered accordingly. This guarantees that urgent flows are consistently prioritized over less time-sensitive ones.

In addition to priority rules, AMR mission triggers are based on two further logics:

- **Saturation logic** → a mission is triggered once the trolley has reached its full volumetric capacity.
- **Time-out logic** → a mission is triggered after a pre-defined time interval elapses from the scanning of the first package into a trolley, regardless of whether it is fully saturated.

The preliminary configuration of activation triggers for each loading station is summarized in the table 38 below.

Station Number		3			4			5		
Criteria		PRIORITY	SATURATION (# packages)	TIMEOUT (s)	PRIORITY	SATURATION (# packages)	TIMEOUT (s)	PRIORITY	SATURATION (# packages)	TIMEOUT (s)
Time of day	6	2	17	3600	2	17	3600	4	17	14400
	7	2	17	3600	2	17	3600	4	17	14400
	8	2	17	3600	2	17	3600	4	17	14400
	9	2	17	3600	2	17	3600	4	17	14400
	10	2	17	3600	2	17	3600	4	17	14400
	11	2	17	3600	2	17	3600	4	17	14400
	12	2	17	3600	2	17	3600	4	17	14400
	13	2	17	3600	2	17	3600	4	17	14400
	14	1	17	1800	2	17	3600	3	17	7200
	15	1	17	1800	2	17	3600	3	17	7200
	16	1	17	1800	2	17	3600	2	17	3600
	17	1	17	1800	2	17	3600	1	17	1800
	18	1	17	1800	1	17	1800	1	17	1800
	19	2	17	3600	1	17	1800	1	17	1800
	20	3	17	7200	1	17	1800	1	17	1800
	21	3	17	7200	1	17	1800	4	17	14400
	22	3	17	7200	1	17	1800	4	17	14400
	23	3	17	7200	1	17	1800	4	17	14400
	0	3	17	7200	3	17	7200	4	17	14400
	1	3	17	7200	3	17	7200	4	17	14400
	2	3	17	7200	3	17	7200	4	17	14400
	3	3	17	7200	3	17	7200	4	17	14400
	4	3	17	7200	3	17	7200	4	17	14400
	5	3	17	7200	3	17	7200	4	17	14400

Table 38: AMR Mission Trigger Criteria

The table reports, as an illustrative example, only a subset of loading stations (specifically stations 3, 4, and 5). For each of these stations, priority levels and time-out parameters vary according to the time of day, while the saturation threshold remains constant throughout the day. In this preliminary draft, saturation was defined as the maximum number of small packages a trolley can contain, estimated on the basis of the average volume of parcels handled in each packaging zone (A, B, or C). This differentiation is necessary since each packaging zone processes different types of items, characterized by distinct average volumes.

Furthermore, the definition of trigger parameters was supported by a historical volume analysis of the target flow. This analysis was based on data extracted for the period January–May 2025, in order to evaluate typical handling volumes and workload distribution across the day. An example of this analysis is provided in Table 39 below.

	Station number (Packaging Zone A)	3	4	5	6	7	8
	Pre-sorting Group	**Urgent Slot 1**	**Urgent Slot 2**	**Urgent Slot 3**	**Urgent Slot 4**	**Stock**	**Extra-Europe**
Time of day	6	22	5	11	19	19	10
	7	22	8	14	24	20	9
	8	17	5	14	25	18	12
	9	13	5	13	35	22	13
	10	8	4	6	39	19	10
	11	5	6	3	13	7	4
	12	10	7	4	18	10	6
	13	14	6	10	20	11	5
	14	18	7	21	16	13	6
	15	25	10	24	19	9	5
	16	28	7	23	22	10	5
	17	7	5	25	33	8	5
	18	7	4	24	51	10	6
	19	5	3	8	35	6	4
	20	4	5	5	24	5	3
	21	9	7	7	51	13	5
	22	4	3	4	20	6	3
	23	8	2	6	17	5	6
	0	8	5	4	20	5	2
	1	5	3	6	12	3	2
	2	6	4	5	9	6	3
	3	5	1	3	7	3	2
	4	9	5	9	10	6	5
	5	6	4	7	7	5	4

Table 39: Voume Analysis – example

9.3.4. New Process Flow and Expected Results

After analyzing the AS-IS process and defining the TO-BE layout, the new process flow can be described in detail. The redesigned flow combines automation, enabled by the use of AMRs for the movement of trolleys and packages, with manual activities that remain under the responsibility of human operators.

In particular, the TO-BE process will be structured as follows (illustrated in Figure 55). The packaging operator in the BLUMAG and DEMAG areas collects an empty trolley from the dedicated buffer area, each of which is identified by a unique code, and registers it at the assigned loading station, identified by a numerical code as previously described, through the tablet interface. Once the trolley is registered, the operator carries out the packaging activities: preparing the item, applying the label, scanning the barcode, and placing the package inside the trolley corresponding to the designated distribution channel.

For the next steps, the process differs depending on the packaging zones:

- **Packaging Zones B and C (indirect AMR access):** when a trigger condition (e.g., time-out or saturation) is reached and the trolley is ready for transport, the tablet notifies the operator through a visual and/or acoustic signal. The operator manually transfers the trolley to one of the available loading stations in Packaging Zone A (direct AMR access) and links it to the corresponding station number. This registration enables the AMR to identify the exact loading point, approach the station, and initiate the handling mission. If the AMR is transporting an empty trolley, it will first deposit it in the designated area before collecting the full trolley to be transported.
- **Packaging Zone A (direct AMR access):** when a trigger condition occurs, the AMR directly approaches the loading station, drops off an empty trolley if available, and collects the full one without operator intervention.

Once the trolley is collected, the AMR transports it to the designated unloading stations in the Macro UDR area (Shipping department). Here, it deposits the full trolley in one of the available full-trolley unloading stations. If an empty trolley is available, the AMR immediately retrieves it and carries it back to the loading stations, thereby ensuring a continuous full/empty exchange cycle.

At the Macro UDR, the operators in charge of sorting activities retrieve the full trolley and distribute the small packages into their respective final containers for shipment. Once the sorting operations are completed and the trolley has been emptied, it is placed in one of the dedicated empty-trolley stations, where it becomes available for the next AMR mission.

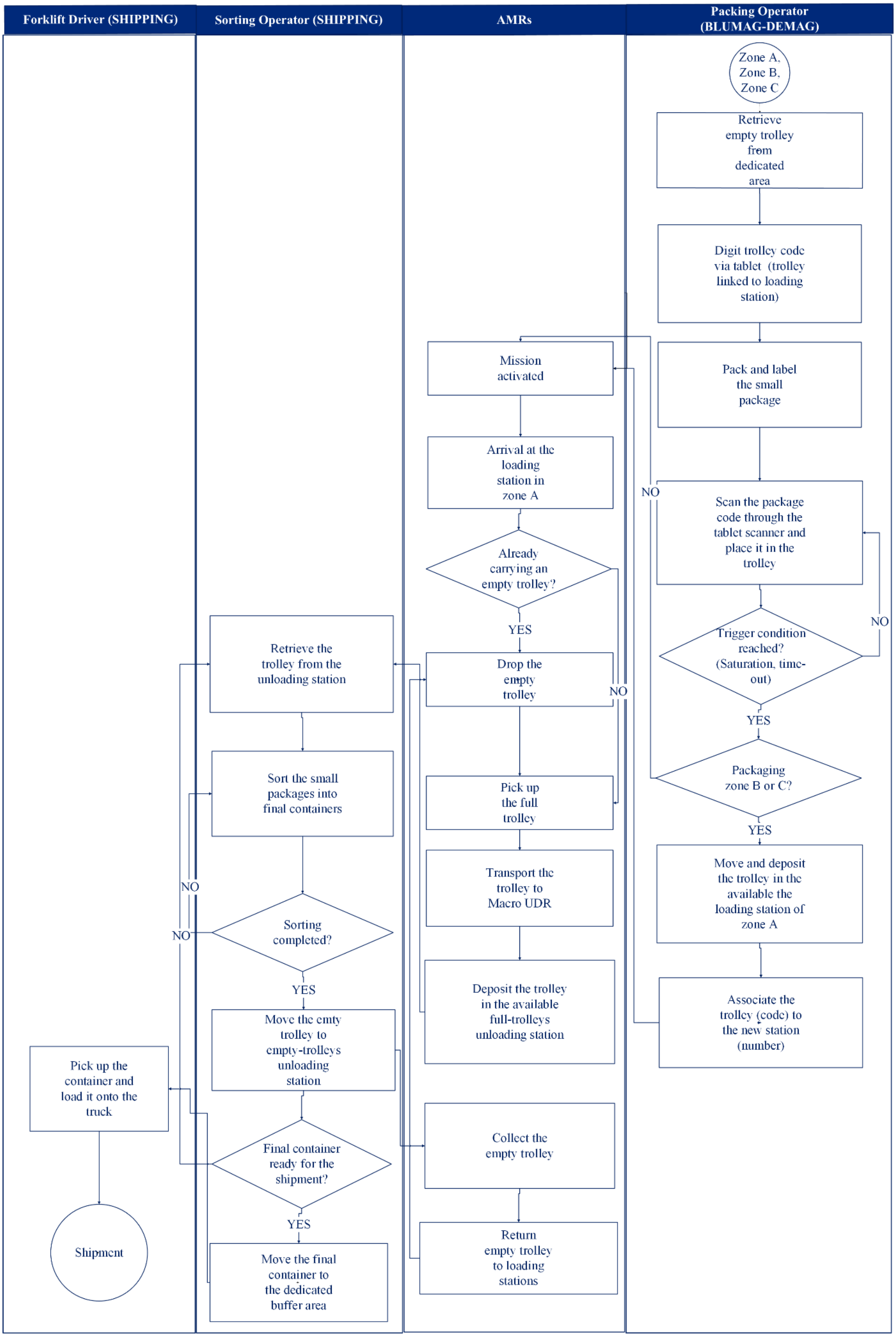

Figure 55: Flow Chart TO-BE Process – After AMR Implementation

After describing in detail, the TO-BE process resulting from the implementation of the solution, the main **strengths** and the **expected results** in terms of KPI improvements can be summarized as follows.

First, the solution will ensure a continuous flow of material, with particular focus on managing "Urgent" items, which are characterized by very short lead times and therefore require fast and uninterrupted transportation from the outflow areas to the Shipping department. Furthermore, the prioritization logic will allow materials to be moved according to actual shipping requirements, thereby improving the accuracy of internal deliveries and accelerating the handling of urgent items.

In addition, the introduction of the AMR management system will enable the scanning and digital registration of packages. This functionality will guarantee a real-time traceability and visibility of material status. Specifically, the Shipping department can check whether a package approaching its shipping deadline is inside a trolley, is currently being transported, or has been deposited in the sorting area. This will eliminate the need for forklift operators to search for missing items in the outflow areas, thus reducing delays and inefficiencies. In addition, the system will allow operators of the shipping department to directly trigger the handling mission for items that are still located in the packaging areas, inside a trolley, avoiding unnecessary searching activities and manual transport activities.

In summary, the main benefits of this solution will be the assurance of a continuous material flow, the full traceability of items, and the reduction of inefficiencies caused by inaccurate internal deliveries. These improvements will be directly reflected in the **expected reduction** of the **Delivery Inaccuracy Rate (DIR)** and, consequently, in the decrease of the time spent by forklift operators **searching for missing packages.**

In detail, the expected result is a **reduction of the DIR by 60%.** This estimation is based on the fact that the solution will only cover the flow of *"small, lightweight, and high-turnover items"* originating from the BLUMAG and DEMAG automated warehouses. In the ideal case, excluding additional anomalies or process inefficiencies, the DIR would **decrease** from the current 59% to approximately **24%.**

Consequently, the average **daily searching time** for forklift operators is also expected to decrease by 60%, from 68.3 h/day to **27.8 h/day**. This reduction implies that the share of searching activities within the total daily time spent in truck loading activities would fall from the current 28% to around **11%.**

All these estimations have been made under the assumption of constant daily volumes, based on the AS-IS measurements. Once the solution will be implemented, however, the

KPIs will be recalculated using actual, real-time data on daily volumes, in order to provide a precise and updated evaluation of the solution's impact on the process.

While the solution described introduces significant improvements in the internal material handling process, it nonetheless presents certain **limitations**, which represent challenges that can be addressed in future developments. The main limitations can be summarized as follows:

- **Limited integration between the Turin warehouse WMS and the AMR management system** → This limitation prevents the AMR management software from having full visibility over the scanned packages, as the only available data are the package code and, indirectly, its status within the AMR system. Consequently, this reduces the level of control and flexibility in managing the flow.
- **Partial coverage of the overall material handling flow** → The solution will apply only to approximately 60% of the total flow. The remaining 40%, comprising other packaged material types remains outside the AMR scope. However, this residual inefficiency can be mitigated through the introduction of traceability on Tugger Train flows, which represents the focus of the next solution described in the following paragraph.

9.4. Tugger Train Sinergy and Material Traceability

The last solution, identified with number (4) in the FMEA, analyzed within this project was developed only at a conceptual stage and is planned to be implemented in 2026. For this reason, also this solution, as the previous one, has been analyzed in this study only with a qualitative and more descriptive approach, without the quantification of its impact on the KPIs analyzed in the Measure phase.

This solution is designed to eliminate the remaining 40% of inefficiency in the Shipping Flow caused by package search activities, thereby ideally reducing the Delivery Inaccuracy Rate (DIR) to 0%, under the assumption of no additional anomalies or process inefficiencies. Furthermore, this solution aims to remove inefficiencies and waiting times between departments caused by the current imbalance in resource allocation, which results from managing two fully separated flows. With this new approach, both the Storage and Shipping flows will be jointly optimized.

The solution foresees the **implementation of a dedicated WMS functionality** that enables the creation of **handling missions for Tugger Trains**, thereby establishing a **dynamic work queue**. Missions will be automatically assigned to the nearest available tugger train driver, based on workload balancing and resource availability. Additionally, the system will introduce **material traceability** during Tugger Train operations, providing real-time visibility on package status. This means that the Shipping department will be able to monitor whether a package is stored in the buffer, loaded onto a Tugger Train, in transit, or already delivered to the sorting area, thus enabling end-to-end visibility of the material flow.

In detail, the **TO-BE process** will be structured as follows. The packaging operator packs and labels the item. If the package is an individual unit or a pallet, it is deposited in the buffer, and the corresponding buffer barcode is scanned to confirm placement. If the package is a small item, it is grouped into a larger carton box, identified by a unique UDR (Unit Delivery Reference) code. The operator scans both the package barcode and the UDR code, thereby associating the package to its container. Once the container reaches a predefined saturation level, or when the time-out is triggered, a pick-to-light system notifies the operator that the container must be moved to the buffer. The operator transfers the container, scans its barcode together with the buffer code, and confirms that it has been placed in the buffer. When the buffer, dimensioned according to the Tugger Train capacity, reaches saturation or its time-out, the pick-to-light system signals that the buffer is ready for loading. At this stage, the forklift operator loads the material deposited into the buffer onto a wagon and scans both the buffer code and the station code. Each station has a unique identifier, allowing the system to generate a

handling mission and communicate the pick-up point. The package status is updated in the system, indicating that the material has been loaded and is awaiting transport.
Once the mission is generated, it is assigned to the nearest available Tugger Train driver, who accepts the mission, moves to the indicated station, collects the load, and transports it to its destination. Upon delivery, the driver closes the mission in the system, and the material status is updated to reflect successful delivery and readiness for unloading. Figure 56 illustrates a schematic representation of the TO-BE process previously described.

Through this solution, the current separation between the Shipping and Storage flows will be eliminated, resulting in a unified fleet of Tugger Train drivers operating dynamically across both flows. Material handling missions will thus be executed according to real-time needs and priority rules, thereby reducing inefficiencies and waiting times caused by resource imbalances. This improvement has been internally referred to as **"Tugger Train Synergy"**.

Regarding this solution, several strengths and weaknesses have been identified in view of its potential implementation. The main strengths lie in the ability to ensure a continuous material flow, reducing inefficiencies and departmental imbalances, while providing flexibility in fleet allocation according to volume fluctuations. Moreover, it removes the need for urgent package searches by the Shipping department, thus improving process reliability and minimizing searching times.
Conversely, challenges remain due to the complexity and heterogeneity of the outflow areas, which hinder the implementation of a uniform traceability system, as well as the intrinsic complexity of the Storage flow, that is characterized by specific material types and complicate documentation for scanning activities.

Future studies will focus on evaluating the trade-off between scanning time and current searching activities, with the objective of defining a standardized approach to ensure effective and uniform traceability across all outflow departments.

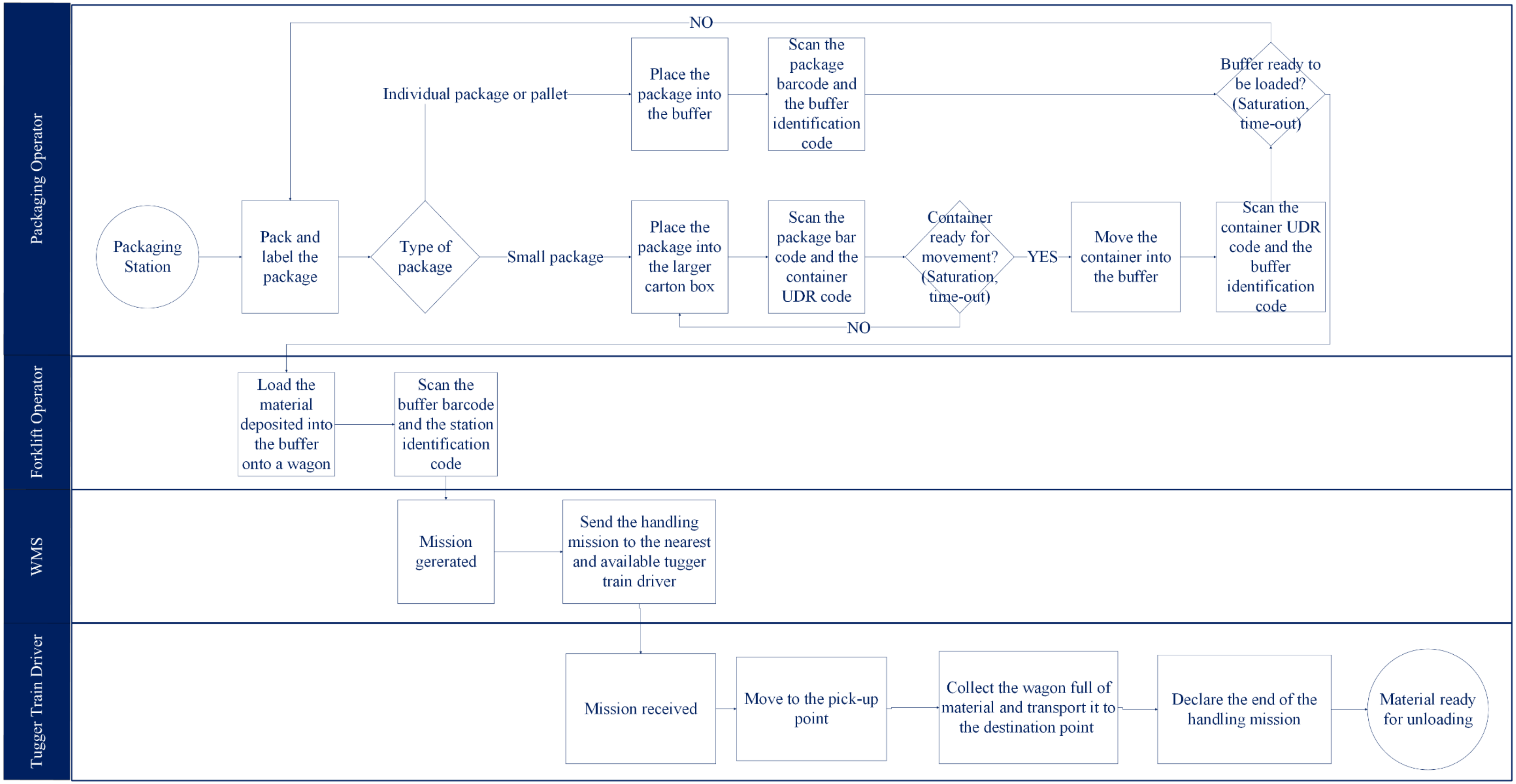

Figure 56: Flow chart TO-BE Process – After Implementation of Tugger Train Sinergy and Traceability Solution

10. Control Phase

After detailing the proposed solutions and the analysis conducted for their implementation, this chapter focuses on monitoring the TO-BE process through the calculation of the KPIs previously measured in the AS-IS phase, in order to evaluate the actual improvements achieved in the material handling process.

It is important to highlight that, at the time of writing this thesis, it is possible to measure the effects only of the **solutions (1) and (2)**, namely the ***Redesign of Internal Routes*** and the ***Introduction of the Hook/Unhook System***. The other two solutions, (3) and (4) have not yet been deployed. For these, only the expected results—already discussed in Sections 9.3 and 9.4—can be considered.

As already described, the two implemented solutions are expected to impact the following KPIs:

- **Redesign of Internal Routes** → reduction of real cycle time (CT) and total process time (PT).
- **Introduction of the Hook/Unhook System** → reduction of unloading/loading time ($T_{u/l}$), decrease in process time (PT), and improvement of Tugger Train efficiency (E).

Both these solutions were implemented together on July 21, 2025. After the go-live, a two-week observation period was carried out, during which data were collected using the same methodology applied in the Measure phase, ensuring consistency in monitoring and KPI calculation for the TO-BE scenario.

In total, 1.350 records were collected for the Storage flow and 1.180 records for the Shipping flow. The results of this analysis are presented in the following sections.

10.1. Cycle Time (CT) Calculation TO-BE Scenario

The expected outcome of the ***Internal route redesign solution (1)*** is a reduction in the **Cycle Time (CT)**, representing the pure handling time. As already described in Section 9.1, through the calculation of the **Distance Traveled (D)** and the **Theoretical Cycle Time (CT_{th})**, an improvement of 21% was estimated compared to the AS-IS scenario, with a 24% improvement for the Storage Flow and 18% for the Shipping Flow. However, since actual handling operations and the resulting **real cycle time** are subject to potential interruptions along the route and variations in travel speed, an intrinsic process inefficiency of 10% has been considered. Taking this into account, the overall improvement can be realistically estimated at 18%, with **21%** for the **Storage Flow** and **16%** for the **Shipping Flow**. The results of the TO-BE measurements, obtained from the new observation period, are reported below.

Storage Flow

For the calculation of the TO-BE Cycle Time (CT), the same routes considered in the AS-IS phase (Table 6, Section 7.2) were used. As in the Measure phase, different transfer types were analyzed, defined as follows:

- **Transfer 1 – Full Load**
- **Transfer 2 – Full Load**
- **Transfer 3 – Empty Load**
- **Transfer 4 – Empty Load**

These transfer categories are described in detail in Section 7.2.3. Each transfer type corresponds to a set of predefined routes, with specific origin and destination points.
For each route within a transfer type, the average cycle time was calculated and subsequently multiplied by the average daily frequency of that route. This allowed for the computation of the total daily cycle time for each transfer type. Finally, the results of all transfer types were aggregated to determine the overall daily cycle time, expressed in hours per day, for the Storage Flow.
The following tables (Tables 40, 41, 42, and 43) present a comparison between the AS-IS and TO-BE results of the cycle time calculations for each transfer type. For the daily cycle time calculation, the same frequencies identified and used in the AS-IS analysis during the Measure phase were adopted.

Origin	Destination	Daily Frequency	Average Cycle Time/route (AS-IS)	Average Cycle Time route/day (AS-IS)	Average Cycle Time/route (TO-BE)	Average Cycle Time route/day (TO-BE)	Changing %
INBOUND	BLUMAG-PUTAWAY	4	00:05:58	00:23:53	00:03:14	00:12:56	-46%
INBOUND	REPACKAGING AREA	19	00:08:16	02:37:12	00:04:38	01:28:11	-44%
INBOUND	KT	1	00:11:50	00:11:50	00:05:21	00:05:21	-55%
INBOUND	P&P 10	3	00:06:13	00:18:40	00:03:14	00:09:42	-48%
INBOUND	P&P 80	13	00:03:57	00:51:23	00:03:46	00:48:54	-5%
INBOUND	SCR-PUTAWAY	23	00:06:06	02:20:24	00:04:52	01:51:58	-20%
INBOUND	SHIPPING	3	00:06:54	00:20:43	00:07:13	00:21:39	4%
Total				**07:04:04**		**04:58:41**	**-30%**

Table 40: Calculation Comparison of Average Cycle Time – Transfer 1 – Storage Flow

Origin	Destination	Daily Frequency	Average Cycle Time/route (AS-IS)	Average Cycle Time route/day (AS-IS)	Average Cycle Time/route (TO-BE)	Average Cycle Time route/day (TO-BE)	Changing %
REPACKAGING AREA	BLUMAG-PUTAWAY	5	00:07:33	00:37:45	00:08:11	00:40:53	**8%**
REPACKAGING AREA	P&P 10	2	00:07:40	00:15:20	00:08:11	00:16:21	**7%**
REPACKAGING AREA	P&P 80	12	00:06:13	01:14:32	00:08:11	01:38:08	**32%**
Total				**02:07:37**		**02:35:22**	**22%**

Table 41: Calculation Comparison of Average Cycle Time – Transfer 2 – Storage Flow

Origin	Destination	Daily Frequency	Average Cycle Time/route (AS-IS)	Average Cycle Time route/day (AS-IS)	Average Cycle Time/route (TO-BE)	Average Cycle Time route/day (TO-BE)	Changing %
BLUMAG-PUTAWAY	INBOUND	6	00:08:48	00:52:48	00:04:01	00:24:07	**-54%**
REPACKAGING AREA	INBOUND	11	00:03:51	00:42:25	00:05:32	01:00:55	**44%**
KT	INBOUND	1	00:09:00	00:09:00	00:06:26	00:06:26	**-29%**
P&P 10	INBOUND	4	00:08:58	00:35:53	00:04:01	00:16:05	**-55%**
P&P 80	INBOUND	18	00:07:01	02:06:22	00:05:01	01:30:15	**-29%**
SCR-PUTAWAY	INBOUND	23	00:05:10	01:58:52	00:04:21	01:39:59	**-16%**
SHIPPING	INBOUND	3	00:08:35	00:25:46	00:06:18	00:18:53	**-27%**
Total				**06:51:07**		**05:16:41**	**-23%**

Table 42: Calculation Comparison of Average Cycle Time – Transfer 3 – Storage Flow

Origin	Destination	Daily Frequency	Average Cycle Time/route (AS-IS)	Average Cycle Time route/day (AS-IS)	Average Cycle Time/route (TO-BE)	Average Cycle Time route/day (TO-BE)	Changing %
BLUMAG-PUTAWAY	REPACKAGING AREA	2	00:09:00	00:18:00	00:03:38	00:07:17	**-60%**
P&P 10	REPACKAGING AREA	1	00:06:33	00:06:33	00:03:38	00:03:38	**-44%**
P&P 80	REPACKAGING AREA	6	00:06:46	00:40:38	00:04:56	00:29:38	**-27%**
Total				**01:05:11**		**00:40:34**	**-38%**

Table 43: Calculation Comparison of Average Cycle Time – Transfer 4 – Storage Flow

From the analysis of the tables above, it emerges that, in general, all transfer categories show an improvement in terms of average daily cycle time per route. The only exception is **Transfer 2,** which records a slight deterioration compared to the AS-IS scenario. However, this effect is offset by the significant improvements observed in the other transfers, resulting in an overall reduction of the total daily cycle time (CT). A summary of the results, comparing the AS-IS and TO-BE scenarios, is reported in Table 44.

Transfer	Average Cycle Time/day (AS-IS)	Average Cycle Time (Hours/day) (AS-IS)	Average Cycle Time/day (TO-BE)	Average Cycle Time (Hours/day) (TO-BE)	Improvement
Transfer 1	07:04:04	7,1	04:58:41	5,0	**-30%**
Transfer 2	02:07:37	2,1	02:35:22	2,6	**22%**
Transfer 3	06:51:07	6,9	05:16:41	5,3	**-23%**
Transfer 4	01:05:11	1,1	00:40:34	0,7	**-38%**
Total		**17,1**		**13,48**	**-21%**

Table 44: Comparison AS-IS vs TO-BE for Cycle Time Calculation – Storage Flow

From the results reported in the table, it can be observed that the overall improvement in the Storage Flow amounts to **21%**, in line with the estimation previously described from the theoretical cycle time (CT_{th}) and the assumed intrinsic process inefficiency. This confirms the expected outcome for the real cycle time (CT).

Shipping Flow

Similarly, for the Shipping Flow, the calculation of the TO-BE cycle time (CT) was based on the same routes considered in the AS-IS phase, as reported in Table 16 of Section 7.3. As in the Measure phase, two types of transfers were analyzed: **Transfer 1 – Full Load** and **Transfer 2 – Empty Load**, described in Section 7.3.3. For each individual route, the average cycle time was calculated and then multiplied by the corresponding daily frequency, in order to determine the average daily cycle time for each route, included in every transfer type. These values were then aggregated to obtain the total daily cycle time, expressed in hours/day, for the Shipping Flow. The following tables (Tables 45 and 46) report a comparison between the AS-IS and TO-BE scenarios for each route, divided by transfer type. As with the Storage Flow, the same daily frequencies were applied to both the AS-IS and TO-BE calculations to ensure consistency in the comparison of daily cycle times.

Origin	Destination	Daily Frequency	Average Cycle Time/route (AS-IS)	Average Cycle Time route/day (AS-IS)	Average Cycle Time/route (TO-BE)	Average Cycle Time route/day (TO-BE)	Changing %
1 R/1 S	SHIPPING	16	00:07:34	02:01:05	00:06:34	01:45:00	**-13%**
BLUMAG-PACKING	SHIPPING	10	00:06:28	01:04:37	00:05:48	00:58:00	**-10%**
DEMAG	SHIPPING	9	00:05:56	00:53:26	00:03:07	00:28:00	**-48%**
SCR-PACKING	SHIPPING	29	00:05:10	02:30:02	00:05:10	02:30:02	**0%**
Total				**06:34:36**		**05:41:02**	**-18%**

Table 45: Calculation Comparison of Average Cycle Time – Transfer 1 – Shipping Flow

Origin	Destination	Daily Frequency	Average Cycle Time/route (AS-IS)	Average Cycle Time route/day (AS-IS)	Average Cycle Time/route (TO-BE)	Average Cycle Time route/day (TO-BE)	Changing %
SHIPPING	1 R/1 S	14	00:05:56	01:23:02	00:04:43	01:06:00	**-21%**
SHIPPING	BLUMAG-PACKING	11	00:04:30	00:49:30	00:04:00	00:44:00	**-11%**
SHIPPING	DEMAG	11	00:05:03	00:55:37	00:04:44	00:52:00	**-6%**
SHIPPING	SCR-PACKING	27	00:05:58	02:41:12	00:05:58	02:41:12	**0%**
Total				**05:49:20**		**05:23:12**	**-7%**

Table 46: Calculation Comparison of Average Cycle Time – Transfer 2 – Shipping Flow

By analyzing the results presented in the two tables above, it can be observed that, overall, all routes across the two transfer categories of the Shipping Flow show improvements. In particular, **Transfer 1** exhibits a more significant reduction of approximately **18%**, while **Transfer 2** achieves a smaller yet positive improvement of around **7%**. These results were then aggregated to calculate the overall average daily cycle time for the Shipping Flow, allowing a direct comparison with both the AS-IS and TO-BE scenarios, reported in table 47.

Transfer	Average Cycle Time/day (AS-IS)	Average Cycle Time (Hours/day) (AS-IS)	Average Cycle Time/day (TO-BE)	Average Cycle Time (Hours/day) (TO-BE)	Improvement
Transfer 1	06:34:36	6,57	05:41:02	5,05	**-18%**
Transfer 2	05:51:36	5,85	05:23:12	5,38	**-7%**
Total		**12,63**		**10,43**	**-13%**

Table 47: Comparison AS-IS vs TO-BE for Cycle Time Calculation – Shipping Flow

Also in this case, the actual improvement of **–13%** is close to the expected result of **–16%**, although the intrinsic process inefficiencies appear to have a slightly greater impact compared to the Storage Flow. Nevertheless, it can be concluded that the improvements anticipated from the implementation of the solution on the cycle time, as estimated through the analysis of the **Distance Traveled (D)** and the **Theoretical Cycle Time (CT_{th})**, have been effectively confirmed by the results obtained for the calculation of the **Cycle Time (CT)**.

10.2. Waiting Time ($T_{u/l}$) Calculation TO-BE Scenario

Regarding the implementation of the solution (2), namely the ***Introduction of the hook/unhook configuration*** in the stations where it was previously missing, as anticipated in the study reported in Section 9.2, the expected improvements concern two main aspects: the reduction of the non–value-added time ($T_{u/l}$) and the establishment of a more stable and less variable process for the full/empty wagon exchange at the various origin and destination stations.

As highlighted in the previous analysis, a preliminary comparison in the AS-IS scenario between stations already equipped with the hook/unhook system and those without it revealed a clear difference: the former showed an average waiting time for loading/unloading operations of less than 5 minutes, while the latter required on average more than 6 minutes.

In the Control phase, the actual waiting times were measured in all stations where the hook/unhook configuration was newly implemented, allowing a direct comparison between the AS-IS measurements and the TO-BE results, reported in Table 48.

Origin	Destination	Daily Frequency	Average Waiting Time Station AS-IS [min]	Average Waiting Time Station TO-BE [min]	Improvement [%]
INBOUND	**SCR-PUTAWAY**	23	8,7	4,4	**-49%**
INBOUND	**BLUMAG-PUTAWAY**	4	7,6	4,0	**-47%**
INBOUND	**REPACKAGING AREA**	19	18,8	5,1	**-73%**
INBOUND	**SHIPPING**	3	8,4	5,0	**-41%**
REPACKAGING AREA	**BLUMAG-PUTAWAY**	5	8,2	3,4	**-59%**
BLUMAG-PUTAWAY	**REPACKAGING AREA**	2	16,0	5,1	**-68%**
P&P 10	**REPACKAGING AREA**	1	14,9	5,2	**-65%**
P&P 80	**REPACKAGING AREA**	6	14,0	4,9	**-65%**
SHIPPING	**1R-1S**	14	12,2	4,5	**-63%**
1 R/1 S	**SHIPPING**	16	7,1	4,5	**-37%**
BLUMAG-PACKING	**SHIPPING**	10	8,8	5,0	**-43%**
DEMAG	**SHIPPING**	9	8,1	4,1	**-49%**
SCR-PACKING	**SHIPPING**	29	7,0	4,7	**-33%**

Table 48: Comparison of Waiting Time (due to loading/unloading) AS-IS vs TO-BE

As shown in the table, the implementation of the hook/unhook configuration led to tangible improvements in the stations where it was introduced. On average, these stations recorded a **53% reduction** in waiting times, confirming the effectiveness of the solution. This improvement directly impacts the aggregated evaluation of the variable $T_{u/l}$, for both the Storage and Shipping flows, reported in tables 49 and 50 below.

Transfer	Average Waiting time [min/day] (AS-IS)	Average Waiting Time [hours/day] (AS-IS)	Average Waiting time [min/day] (TO-BE)	Average Waiting Time [hours/day] (TO-BE)	Improvement [%]
Transfer 1	670,00	11,17	283,00	4,72	**-57%**
Transfer 2	59,00	0,98	53,00	0,88	**-28%**
Transfer 3	563,00	9,38	563,00	9,38	**0%**
Transfer 4	130,00	2,17	44,00	0,73	**-66%**
Total		**23,70**		**15,72**	**-34%**

Table 49: Comparison Tu/l AS-IS vs TO-BE – Storage Flow

Transfer	Average Waiting time [min/day] (AS-IS)	Average Waiting Time [hours/day] (AS-IS)	Average Waiting time [min/day] (TO-BE)	Average Waiting Time [hours/day] (TO-BE)	Improvement [%]
Transfer 1	485	8,08	298,00	4,97	**-39%**
Transfer 2	354,1	5,90	240,81	4,01	**-32%**
Total		**13,99**		**8,98**	**-36%**

Table 50: Comparison Tu/l AS-IS vs TO-BE – Shipping Flow

The results demonstrate a significant reduction in waiting times related to loading and unloading activities, represented by the variable $T_{u/l}$, in both the Storage and Shipping flows, with improvements of **-34%** and **-36%** respectively. Although these values are slightly lower than the improvement observed at the single-station level reported in Table 48 (average -53%), this difference is explained by the fact that stations already equipped with the hook/unhook configuration did not show further gains, thereby reducing the overall percentage improvement. Nevertheless, the achieved results remain highly relevant, as they correspond to a **reduction of approximately 8 h/day in the Storage flow and 5 h/day in the Shipping flow.**

The second aspect to be considered, which is directly influenced by the implementation of the *hook/unhook configuration*, concerns the **reduction in the variability** of waiting times associated with loading and unloading activities. This improvement is achieved through the creation of a more stable and standard process for the full/empty wagon exchange at both the origin and destination points of the material handling flow performed by Tugger Trains. As highlighted in the implementation study of this solution (Section 9.2), stations where the hook/unhook system was not previously available exhibited a significantly higher variability in the distribution of waiting time measurements (expressed in terms of minutes) for loading and unloading operations, with a higher standard deviation compared to stations already equipped with the configuration.

The following analysis provides a comparison between the AS-IS and TO-BE scenarios for two representative stations where the hook/unhook system has been implemented, specifically SCR-PUTAWAY and 1R–1S.

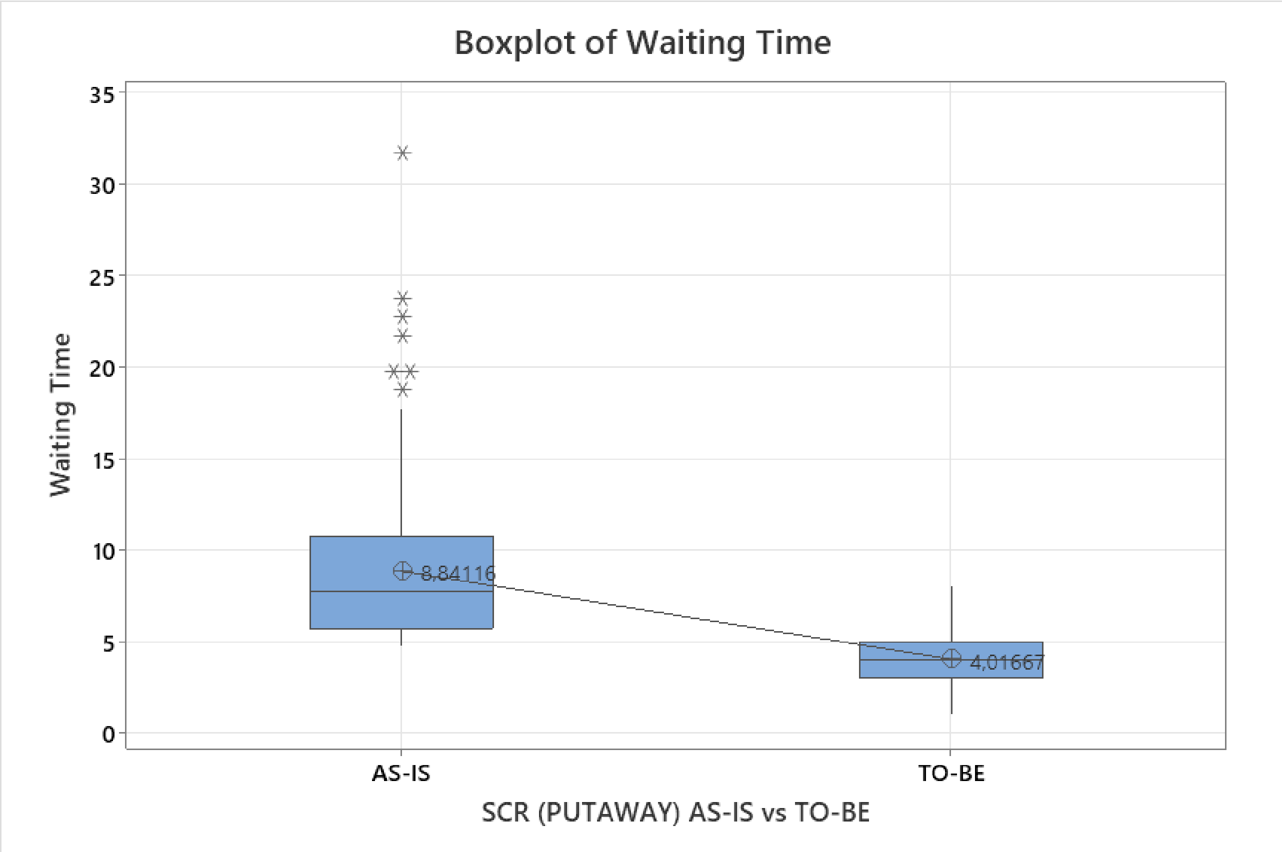

Figure 57: Comparison AS-IS vs TO-BE Waiting Time Data Distribution – SCR (PUTAWAY)

As shown in the box plot in Figure 57, the distribution of waiting time measurements at the **SCR-PUTAWAY** station exhibits a significantly lower variability in the TO-BE scenario compared to the AS-IS situation, as a direct result of the introduction of the hook/unhook system. This reduced variability is visible in the narrower interquartile range of the box plot. Moreover, the graph highlights a substantial reduction in the mean waiting time, which decreased from 8.84 to 4.02 minutes.

Specifically, the **TO-BE standard deviation** is **1.98 minutes**, as reported in the graphical summary in Figure 58, considerably lower than the **AS-IS** value of **4.37 minutes,** reported in Figure 59. Finally, Figure 60 presents a Time Series Plot, which provides a clearer representation of the data distribution and allows for a better understanding of the dispersion of individual values relative to the mean.

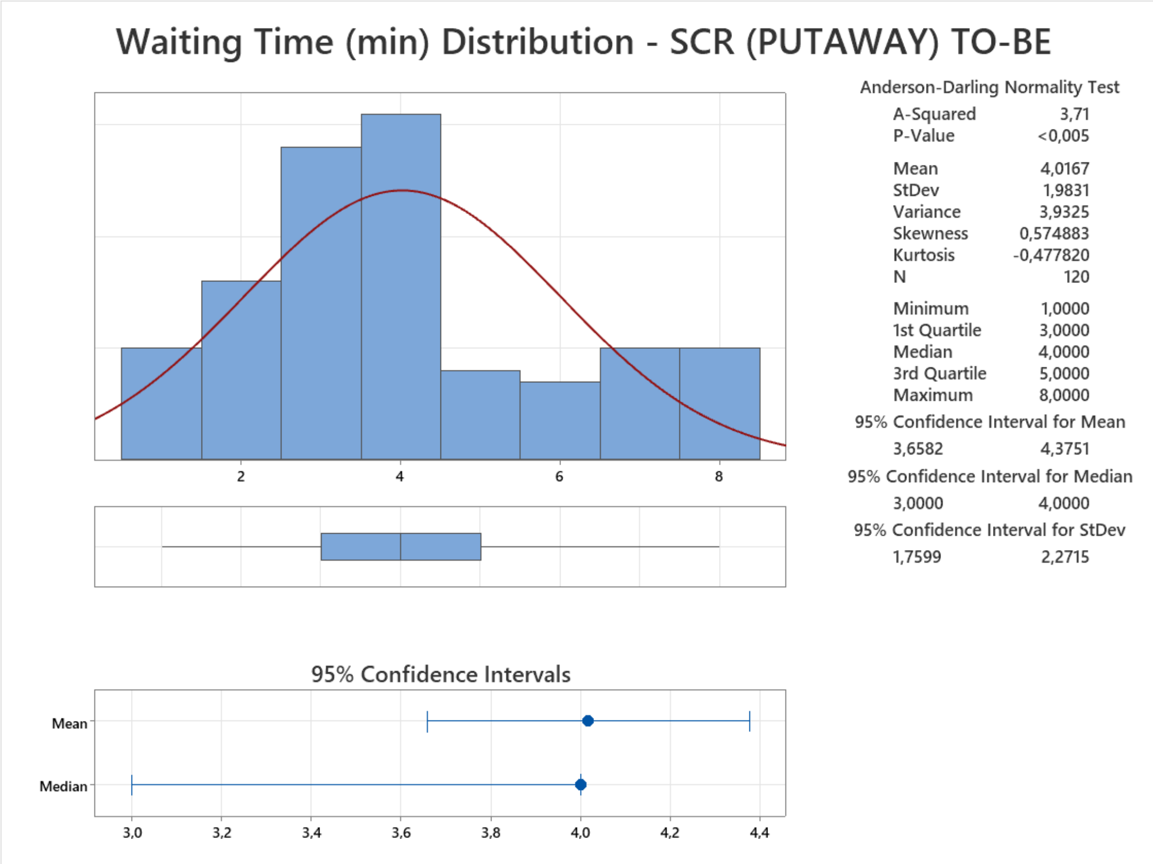

Figure 58: Data Distribution Waiting Time - SCR(PUTAWAY) TO-BE

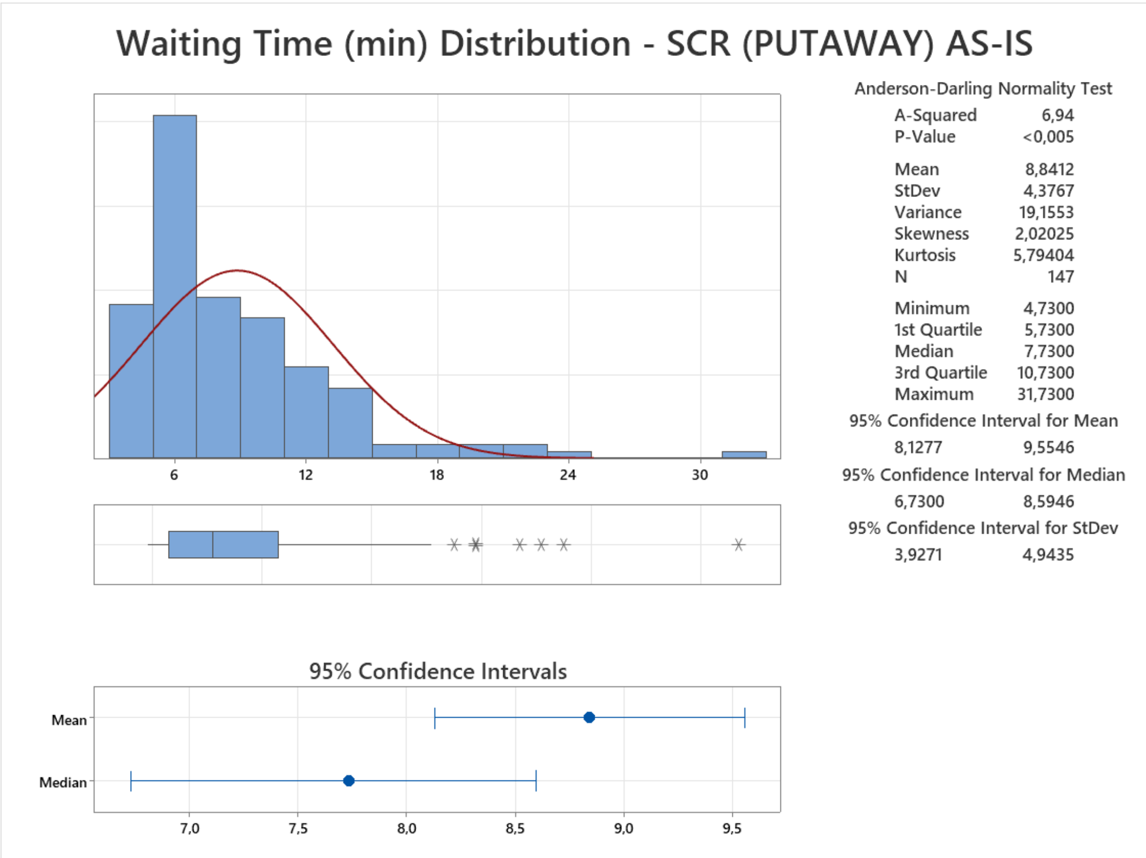

Figure 59: Data Distribution Waiting Time - SCR(PUTAWAY) AS-IS

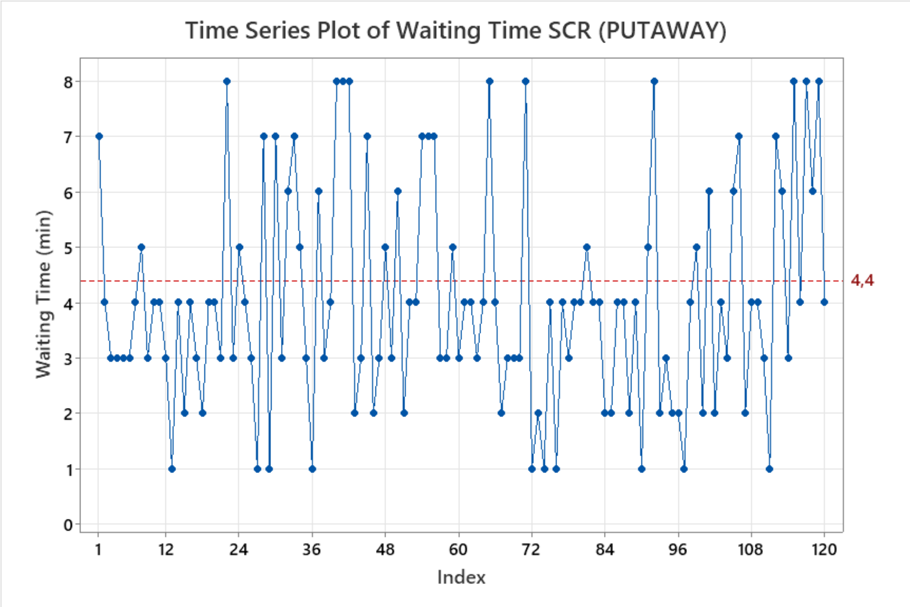

Figure 60: Time Series Plot - Waiting Time Distribution SCR (PUTAWAY) TO-BE

The second station analyzed as representative example is **1R–1S**, located within the Shipping flow. As shown in the box plot in Figure 61, the variability in the distribution of waiting time measurements significantly decreased compared to the **AS-IS** scenario, with the **standard deviation** dropping from **12.71 minutes**, as reported in the graphical summary in Figure 63, to **1.42 minutes** in the **TO-BE** scenario (Figure 62), following the implementation of the hook/unhook configuration. Despite this substantial reduction in variability, a few outliers are still present. However, as already highlighted in the case of the SCR (PUTAWAY) station, these deviations are linked to exceptional conditions external to the standard process.

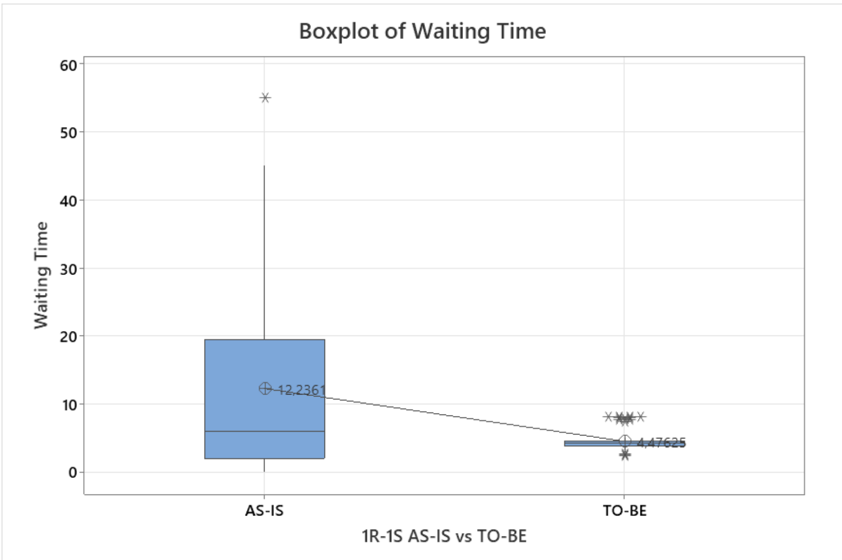

Figure 61: Comparison AS-IS vs TO-BE Waiting Time Data Distribution – 1R-1S

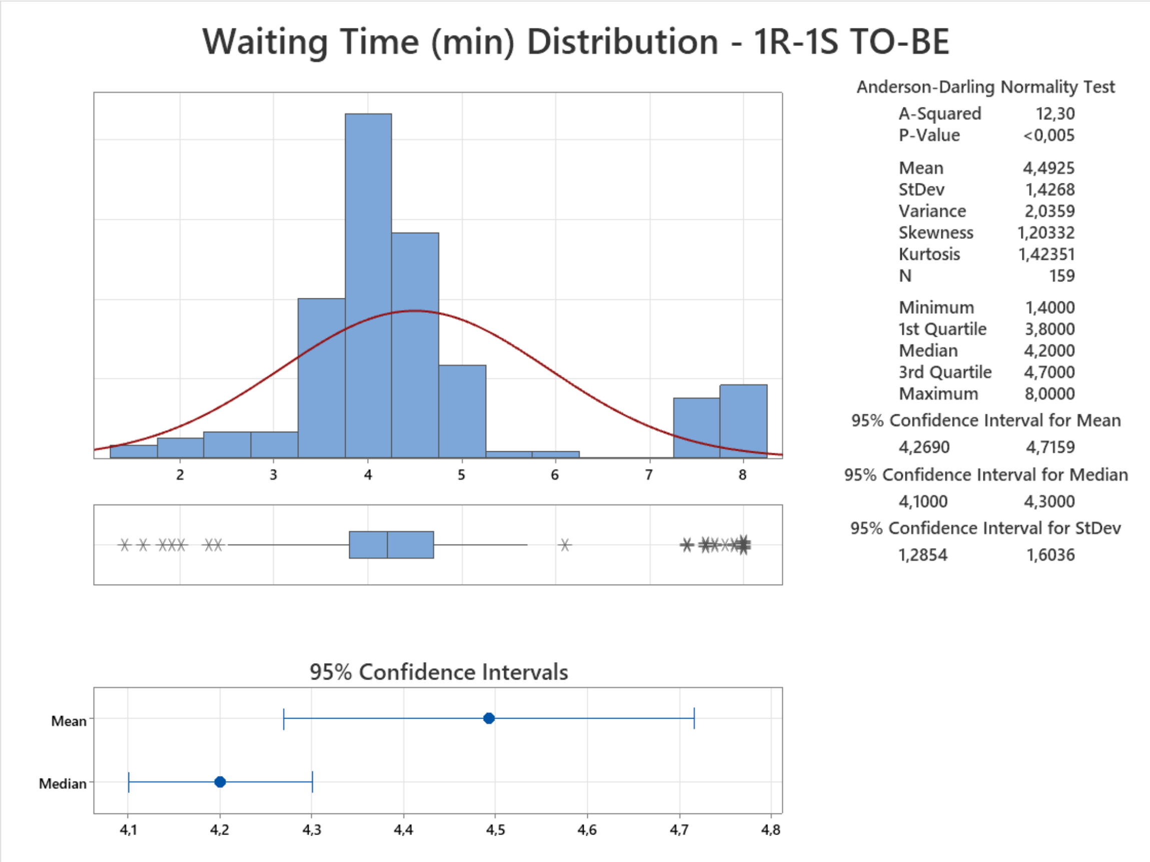

Figure 62: Data Distribution Waiting Time – 1R-1S TO-BE

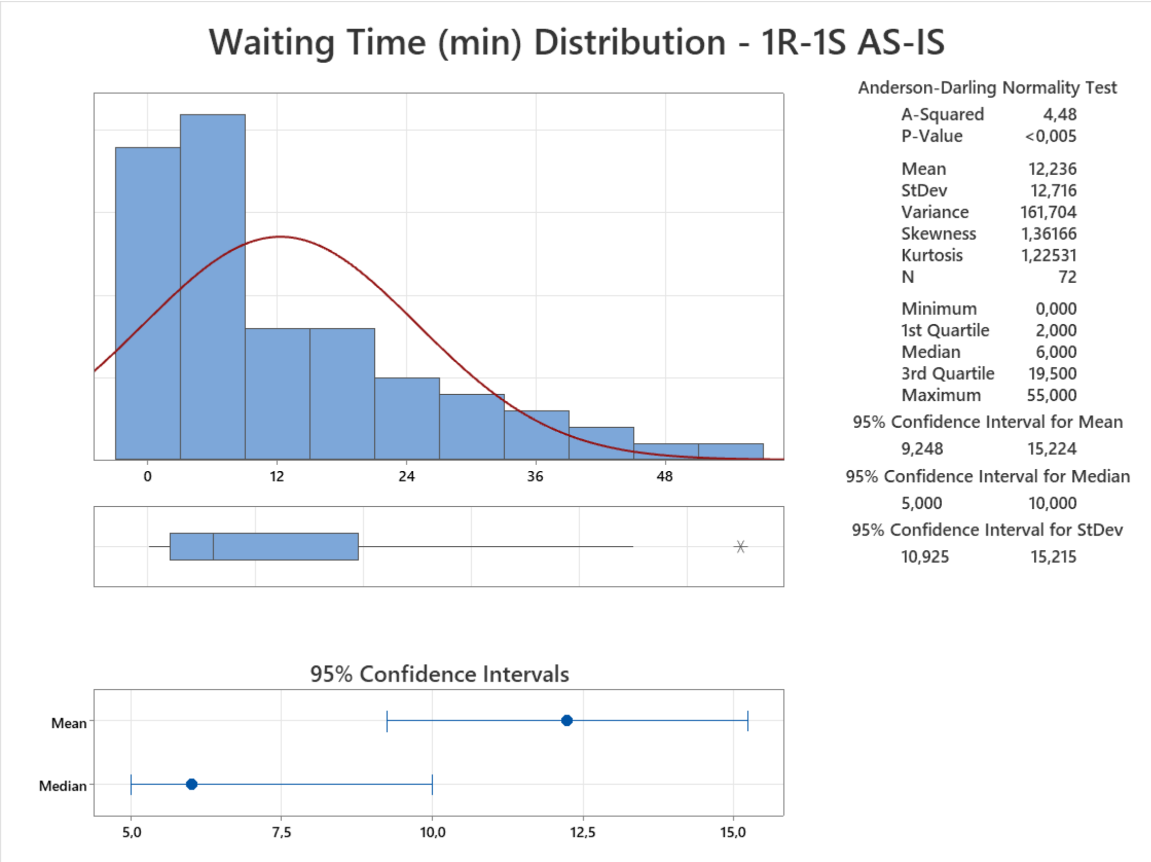

Figure 63: Data Distribution Waiting Time – 1R-1S AS-IS

Finally, Figure 64 presents a time series plot, which provides a clearer visualization of the data distribution for station 1R–1S in the TO-BE scenario.

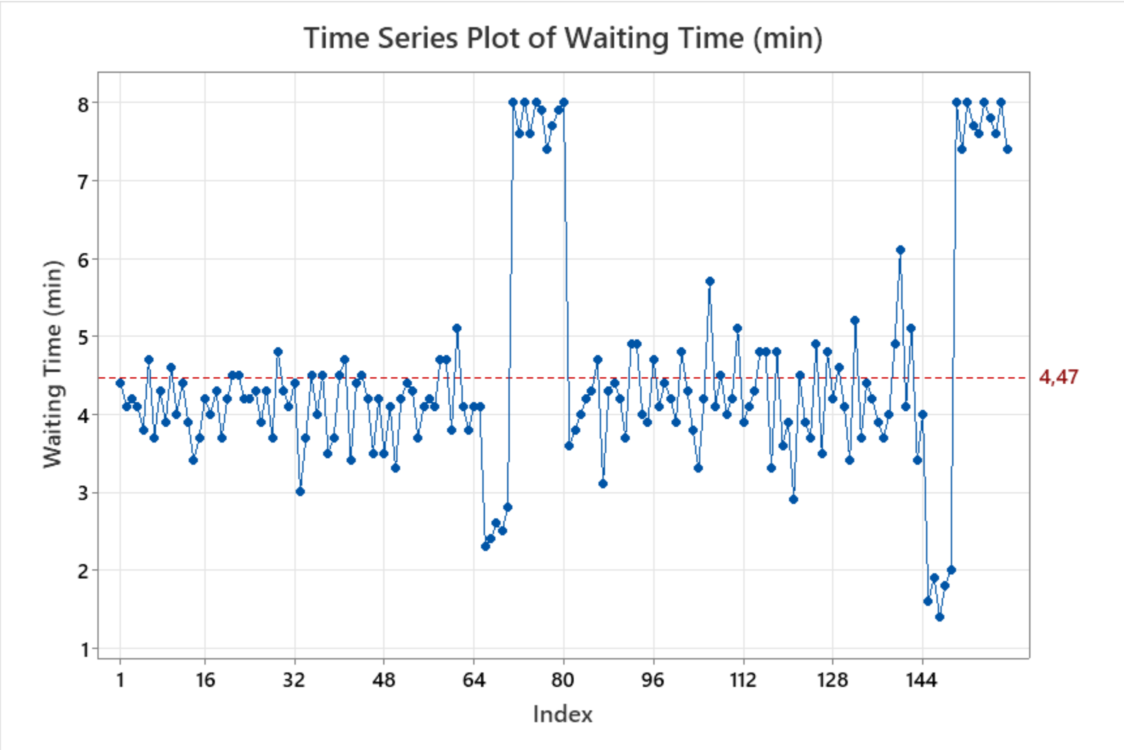

Figure 64: Time Series Plot - Waiting Time Distribution 1R-1S TO-BE

10.3. Process Time (PT) and Efficiency (E) Calculation TO-BE Process

As final step, the KPIs **Process Time (PT)** and **Tugger Train Efficiency (E)** were recalculated, comparing the AS-IS and TO-BE scenarios. Tables 52 and 53 below present the AS-IS versus TO-BE results for both the Storage and Shipping flows.

KPI/Variable	Average Time [Hours/day] AS-IS	% AS-IS	Average Time [Hours/day] TO-BE	% TO-BE	Changing
CT	17,12	33%	13,48	**34%**	**-21%**
$T_{u/l}$	23,70	46%	15,72	39%	**-34%**
T_w	10,77	21%	10,77	27%	**0%**
PT	**51,58**		**39,97**		**-23%**

Table 51: Final KPI Comparison AS-IS vs TO-BE - Storage Flow

KPI/Variable	Average Time [Hours/day] AS-IS	% AS-IS	Average Time [Hours/day] TO-BE	% TO-BE	Changing
CT	12,63	39%	11,07	**42%**	-12%
$T_{u/l}$	13,99	43%	8,98	34%	-36%
T_w	6,15	19%	6,15	23%	0%
PT	**32,77**		**26,20**		**-20%**

Table 52: Final KPI Comparison AS-IS vs TO-BE - Shipping Flow

Analyzing the results reported in the tables, it can be observed that both flows achieved a reduction in total **Process Time (PT),** equal to **-23%** for the Storage Flow and **-20%** for the Shipping Flow. These correspond to a decrease of 11.61 h/day and 6.57 h/day, respectively. In addition, a slight improvement in **Tugger Train Efficiency (E)** is also observed. This indicator is calculated as the ratio between the Cycle Time (CT), which represents the effective time spent in handling activity, and the total process time, which also includes non-value-added times such as $T_{u/l}$ and T_w, according to the following formula:

$$E\% = \frac{CT}{PT}\,x\,100 = \frac{CT}{CT + Tu\_l + Tw}\,x\,100$$

The Tugger Train efficiency (E), measured as a percentage, increased from 33% to **34%** for the **Storage Flow** and from 39% to **42%** for the **Shipping Flow**. This variation appears relatively limited because, although the reduction of $T_{u/l}$ contributed to lowering one of the factors in the denominator of the efficiency formula, the other denominator component, T_w, remained unchanged. At the same time, the numerator (CT) also varied, partially offsetting the effect of the $T_{u/l}$ reduction. As a result, the overall percentage improvement in Tugger Train Efficiency is less pronounced.

11. Conclusion and Future Developments

As highlighted by the comparison between the AS-IS and TO-BE scenarios for the specific KPIs effectively measured, the implemented solutions have led to a tangible optimization of the process. In particular, they effectively reduced non–value-added activities, such as waiting times during loading and unloading operations, but also necessary non–value-added activities and value-added activities included in the material handling cycle time. Tables 53 and 54 below reports the results of the KPIs in the TO-BE scenario, compared to the AS-IS situation, with a calculation of the improvement in term of percentage with respect to the initial value.

Variable/KPI	AS-IS	TO-BE	Δ%
$T_{u/l}$ [hours/day]	23,70	15,72	**-34%**
CT [hours/day]	17,11	13,48	**-21%**
PT [hours/day]	51,58	39,97	**-23%**
E [%]	33%	34%	**+1%**
D [kilometers/day]	110,7	82,7	**−21%**
CT_{th} [hours/day]	15,8	12,5	**−21%**

Table 53: KPIs Results (AS-IS vs TO-BE) - Storage Flow

Variable/KPI	AS-IS	TO-BE	Δ%
$T_{u/l}$ [hours/day]	13,99	8,98	-36%
CT [hours/day]	12,63	11,07	-12%
PT [hours/day]	32,77	26,20	-20%
E [%]	39%	42%	+3%
D [kilometers/day]	66,7	56,0	−16%
CT_{th} [hours/day]	9,5	8,0	−16%

Table 54: KPIs Results (AS-IS vs TO-BE) - Storage Flow

Specifically, the Storage Flow achieved a **23%** reduction in **Process Time (PT)** and a **21%** reduction in **Cycle Time (CT)**, while the Shipping Flow recorded a **20%** reduction in Process Time and a **12%** decrease in Cycle Time. Both flows also showed a decrease in average distance (D), indicating more efficient route utilization.

In addition, the solution (2) had a significant impact on the loading/unloading time **($T_{u/l}$)**, reducing it by **34%** in the Storage Flow and by **36%** in the Shipping Flow. This reduction in average waiting time was further accompanied by a decrease in variability, as discussed in Section 10.2.

Finally, a slight improvement in **Efficiency (E)** was observed, confirming an overall enhancement in process balance and resource utilization.

Overall, these improvements validate the effectiveness of the solution (1) for the Redesign of the Internal Routes, combined with the solution (2) for the implementation of the Hook/Unhook system at the origin and destination point of the routes.

This improvement, demonstrated and measured during the Control phase of the project, allowed the process to become faster and more efficient, thereby achieving one of the main objectives defined during the initial project analysis.

In addition, the implementation of the last two solutions, (3) and (4), is expected to generate further improvements, which will be monitored and measured in the future to validate the estimated results. Specifically, solution (3), concerning the implementation of AMRs, is expected to reduce the Delivery Inaccuracy Rate (DIR) and the time spent searching for missing packages, thanks to the establishment of a continuous and traceable flow. Solution (4), involving the introduction of a mission management and real-tracking system, aims instead to reduce idle times for tugger train drivers caused by the current imbalance of resources and the strict separation of storage and shipping flows. The purpose will be to create a unified flow, managed dynamically through a mission assignment system according to handling needs.
The implementation of these two additional solutions will allow the achievement of the remaining objectives defined in the project's initial phase, ensuring that the material handling process within the Turin warehouse becomes not only more efficient, but also fully traceable and flexible.

Another important consideration is that this project demonstrates how, using a structured methodology, specifically the DMAIC cycle, it is possible to analyze and measure processes in detail, identify the real root causes of inefficiencies, and consequently design targeted and sustainable improvement solutions. This approach enabled the identification of the first two solutions, (1) and (2), which, despite being relatively simple and requiring minimal investment in terms of time and cost, proved to be effective for optimizing the material handling process. Furthermore, the use of technological tools, such as AMRs, will allow the warehouse to reach higher levels of operational efficiency, demonstrating how the introduction of Industry 4.0 technologies represents a fundamental driver for improvement in warehouse and logistics contexts such as the one under study.

Finally, in line with the principle of continuous improvement, every process can always be further optimized and enhanced; hence future analyses and studies will therefore focus on identifying additional opportunities for improvement.

References

Faveto, A., Traini, E., Bruno, G., & Chiabert, P. (2024). based method for evaluating key performance indicators: an application on warehouse system. *The International Journal of Advanced Manufacturing Technology*, *130*(1), 297-310.

Chakma, A. (2024). Determining the key performance indicators for managing the warehouse performance: a case study of international logistic company.

Vuong Jr, H. T. (2020). Monitoring and managing KPIs of material handling performance in operative logistics.

Gu, J., Goetschalckx, M., & McGinnis, L. F. (2007). Research on warehouse operation: A comprehensive review. *European journal of operational research*, *177*(1), 1-21.

Higginson, J. K., & Bookbinder, J. H. (2005). Distribution centres in supply chain operations. In *Logistics systems: Design and optimization* (pp. 67-91). Boston, MA: Springer US.

Baker, P. (2007). An exploratory framework of the role of inventory and warehousing in international supply chains. *The International Journal of Logistics Management*, *18*(1), 64-80.

Richards, G. (2025). *Warehouse management: The definitive guide to improving efficiency and minimizing costs in the modern warehouse*. Kogan Page Publishers.

Huan, S. H., Sheoran, S. K., & Wang, G. (2004). A review and analysis of supply chain operations reference (SCOR) model. *Supply chain management: An international Journal*, *9*(1), 23-29.

Christopher, M. (2011). *Logistics and supply chain management: creating value-adding networks*. Pearson education.

Sgro, M. (2023). *Analisi del nuovo magazzino automatizzato installato presso il centro ricambi IVECO (Torino), gestito dall'operatore logistico KUEHNE+ NAGEL= Analysis of the new automated warehouse installed at the IVECO spare parts facility (Turin), managed by logistics operator KUEHNE+ NAGEL* (Doctoral dissertation, Politecnico di Torino).

Baker, P., & Canessa, M. (2009). *Warehouse design: A structured approach. European Journal of Operational Research*, 193(2), 425–436.

Baker, P. (2004). Aligning distribution center operations to supply chain strategy. *The International Journal of Logistics Management*, 15(1), 111–123.

Kamali, A. (2019). *Smart Warehouse vs. Traditional Warehouse – Review*.

Odeyinka, T., & Omoegun, A. (2023). *Warehouse Operations: An Examination of Traditional and Automated Approaches in Supply Chain Management*.

Masuti, P. M., & Dabade, U. A. (2019*). Lean manufacturing implementation using value stream mapping at excavator manufacturing company.* Materials Today: Proceeding

Möldner, A. K., Garza-Reyes, J. A., & Kumar, V. (2020). *Exploring lean manufacturing practices' influence on process innovation performance.* Journal of Business Research, 106, 233–249.

Purushothaman, M. B., Seadon, J., & Moore, D. (2020). *Waste reduction using lean tools in a multicultural environment*. Journal of Cleaner Production

Bluvband, Z., & Grabov, P. (2009, January). Failure analysis of FMEA. In *2009 Annual Reliability and Maintainability Symposium* (pp. 344-347). IEEE.

Cagliano, A. C., Grimaldi, S., & Rafele, C. (2011). A systemic methodology for risk management in healthcare sector. *Safety Science*, *49*(5), 695-708.

De Mast, J., & Lokkerbol, J. (2012). An analysis of the Six Sigma DMAIC method from the perspective of problem solving. *International Journal of Production Economics*, *139*(2), 604-614.

Karim, N. H., Abdul Rahman, N. S. F., Md Hanafiah, R., Abdul Hamid, S., Ismail, A., Abd Kader, A. S., & Muda, M. S. (2021). Revising the warehouse productivity measurement indicators: ratio-based benchmark. *Maritime Business Review*, *6*(1), 49-71.

https://it.kuehne-nagel.com/it/

https://mobile-industrial-robots.com/it/blog/agv-vs-amr