Integrating Production and Logistics Centre Operations for Enhanced Efficiency in Custom Gates Manufacturing: A Case Study

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Master's Dissertation

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Abstract

This dissertation presents the work conducted in an aluminium gates company with the objective of enhancing productivity in its production and logistics operations and reducing lead time through the integration of the manufacturing unit with the logistics centre, and the implementation of *Kaizen* methodologies. The company's awareness of waste and non-value-added activities, coupled with its medium-term growth projections, prompted the need of greater industrial unity and operational integration.

To achieve this goal, methodologies derived from the Total Flow Management model were employed, including Warehouse Design and Standard Work. Initially, the logistics centre's layout was redesigned to facilitate the transition to new facilities. Subsequently, the manufacturing unit also relocated to the same site, enabling the integration of production and logistics operations through the implementation of a despicking cell. The subsequent implementation of a Warehouse Management System (WMS) aimed to streamline logistical operations. These actions, supported by Standard Work principles to ensure optimal practices, yielded a 32% increase in productivity within the logistics centre, surpassing the predefined target of 15%.

Furthermore, an initiative was undertaken in the manufacturing unit to improve productivity, resulting in the integration of two sectors and an overall productivity gain of 8%.

The dissertation concludes by offering recommendations for future endeavors, such as the development of additional functionalities within the WMS, including task prioritization, which may impact the company's service level and the logistics centre productivity. Additionally, optimizing production planning in the cutting sector is proposed as a means to enhance productivity in the manufacturing unit.

These findings and recommendations contribute to the overall understanding of productivity enhancement and operational integration in manufacturing and logistics environments. The insights gained from this study can inform similar organizations seeking to optimize their processes and achieve efficient integration across different operational units.

Resumo

Esta dissertação apresenta o trabalho realizado numa empresa de portões de alumínio com o objetivo de aumentar a produtividade nas suas operações de produção e logística e reduzir o *lead time* através da integração da unidade de produção com o centro logístico, e a implementação de metodologias *Kaizen*. A consciencialização da empresa em relação a atividades sem valor acrescentado e desperdícios, juntamente com as projeções de crescimento a médio prazo, motivaram a necessidade de uma maior unidade industrial e integração operacional.

Para alcançar este objetivo, foram utilizadas metodologias derivadas do modelo de Gestão de Fluxo Total, incluindo o Design de Armazém e o Trabalho Padronizado. Inicialmente, o layout do centro logístico foi redesenhado para facilitar a transição para novas instalações. Posteriormente, a unidade de produção também foi transferida para o mesmo local, permitindo a integração das operações de produção e logística através da implementação de uma célula de *despicking*. A implementação subsequente de um *Warehouse Management System* (WMS) visou otimizar as operações logísticas. Estas ações, suportadas pelos princípios do *Standard Work*, resultaram num aumento de 32% na produtividade dentro do centro logístico, ultrapassando o objetivo inicialmente definido de 15%. Além disso, foi realizada uma iniciativa na unidade de produção com o objetivo de melhorar a produtividade, resultando na integração de dois setores e num ganho geral de produtividade de 8%.

A dissertação conclui com recomendações para futuras iniciativas, como o desenvolvimento de funcionalidades adicionais no WMS, incluindo a priorização de tarefas, que podem ter impacto no nível de serviço da empresa e na produtividade do centro logístico. Além disso, propõe-se a otimização do planeamento da produção no setor de corte como forma de aumentar a produtividade na unidade de produção.

Estas conclusões e recomendações contribuem para a compreensão geral da melhoria da produtividade e da integração operacional em ambientes de produção e logística. As informações obtidas neste estudo podem orientar organizações similares que procuram otimizar os seus processos e alcançar uma integração eficiente entre diferentes unidades operacionais.

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The completion of this master thesis has been a formidable challenge that I have had the privilege to undertake. Undoubtedly, it has been an arduous and demanding journey, yet one that has provided me with invaluable learning experiences and fills me with a sense of pride. However, none of this would have been achievable without the unwavering support and belief bestowed upon me by numerous individuals who have played an integral role in my academic and personal growth.

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To my family, with a special note to my parents, what I am today is because of you and your belief in me. You encouraged me to follow my passions and you always ensured I had everything I ever needed, no matter how much effort it required from you. The values you have instilled in me are the foundation of this journey, that is still just beginning.

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"Success is 1% inspiration, 98% perspiration and 2% attention to detail."

Phil Dunphy, Modern Family

Contents

Acronyms and Symbols

KPI	Key Performance Indicator
MTO	Make-To-Order
MTS	Make-To-Stock
WIP	Work In Progress
FIFO	First-In-First-Out
CAGR	Compound Annual Growth Rate
WMS	Warehouse Management System
ERP	Enterprise Resource Planning
TMS	Transportation Management System
B2B	Business-To-Business
DIFOTIS	Delivery In Full, On Time, and In Specification
IoT	Internet of Things
ML	Machine Learning
AI	Artificial Intelligence
WCS	Warehouse Control System
AGV	Automated Guided Vehicle
KBS	Kaizen Business System
TPS	Toyota Production System
VA	Value-Added
SMED	Single Minute Exchange of Die
MU1	Manufacturing Unit 1
MU2	Manufacturing Unit 2
MU3	Manufacturing Unit 3

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Chapter 1

Introduction

1.1 Context

This dissertation is based on a project conducted at Kaizen Institute Western Europe, a consulting company specializing in supporting organizations in developing a sustainable competitive advantage through the adoption of a Continuous Improvement culture. The project consists of two main phases: the diagnosis and solution design phase, followed by the implementation phase.

For confidentiality reasons, the company under study is referred to as Company X. Company X operates in the industry of manufacturing aluminium gates and is experiencing growth. To facilitate further expansion and enhance operational efficiency, the decision was made to construct a larger industrial facility that would consolidate all operations. Initially, the company maintained several small logistics centres to serve three different manufacturing units. The first step towards integration involved merging one of the manufacturing units with a new centralized logistics centre. This integration necessitated a redesign of certain processes, presenting an opportunity to improve productivity and leverage the transformative potential associated with the change in location.

Therefore, the project at hand addresses the need to reassess and design the layout of the new logistics centre to ensure seamless integration between production and logistics operations, along with the integration of other initivatives to ensure a productivity increase in its' operations. Additionally, the project aims to increase the overall productivity of the manufacturing unit, thereby boosting the factory's output and enabling it to meet the projected growth in demand.

1.2 Kaizen Institute Consulting Group

Kaizen Institute Consulting Group is a multinational consulting company that originated in Japan and was established by Masaaki Imai in Zug, Switzerland in 1985 (Kaizen Institute, 2023). Despite its relatively recent establishment, the company has emerged as the most experienced consulting firm in the application of the Kaizen methodology, which is rooted in the concept of Continuous

Improvement. The primary objective of the company is to assist organizations in achieving operational excellence by optimizing their processes and providing the necessary resources to sustain performance and continuous improvement across technical, cultural, and leadership aspects.

As depicted in Figure 1.1, Kaizen Institute Consulting Group operates in over 60 countries, spanning more than 45 industries. The company boasts a team of over 1000 specialized consultants who possess extensive expertise in implementing the Kaizen methodology and supporting organizations in their improvement journey. With a global presence and a wide range of industry experience, the company is well-positioned to cater to the diverse needs of its clients and drive positive change in various sectors.

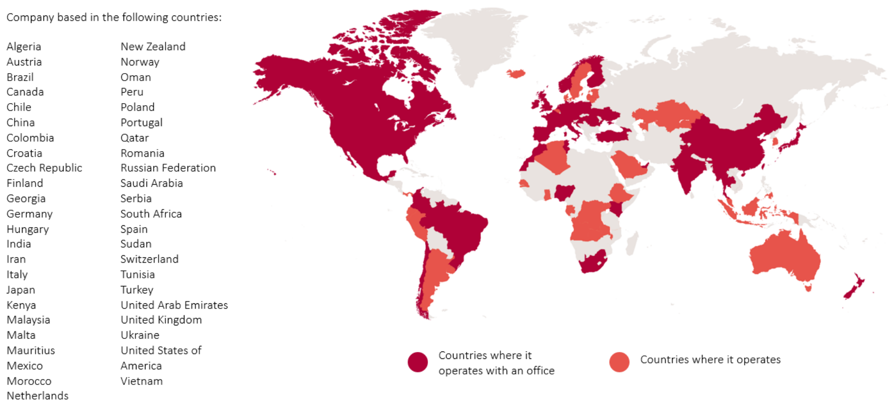

Figure 1.1: Kaizen Institute Consulting Group's global distribution (Institute, 2023a)

1.3 Company X and the Aluminium Gates Industry

Company X was established in the mid-1990s as a manufacturer of high-quality aluminum panels for various applications, particularly in entrance doors. Over the years, the company has gained a prominent presence in the Portuguese market, with its panels being widely utilized in the majority of entrance doors sold in the country. With a focus on expansion, the company ventured into the international market in the early 2000s, making exports its primary objective. Ever since, the company has been diversifying its portfolio and has introduced finished products, one of them being aluminium gates.

The past few years have marked significant milestones for Company X, as it has solidified its position as the leading European producer of aluminium gates. This accomplishment has been accompanied by a remarkable expansion in its sales, predominantly driven by exports. The company's substantial growth has yielded positive outcomes, as evidenced by its robust financial performance, with revenues nearing €100 million.

Through its dedication to quality, innovation, and diversification, Company X has emerged as a prominent player in the aluminum gates industry. Its continued success and commitment to excellence have positioned the company for an expected 20% growth in the next five years.

The demand for aluminum gates has been steadily increasing due to factors such as urbanization, infrastructure development, and the growing emphasis on residential and commercial security. Aluminum gates are widely used in residential properties, commercial buildings, industrial facilities, and public spaces. The Residential Aluminum Gates market is expected to grow annually by 11% coumpound annual growth rate (CAGR) (Watch, 2023). Key factors contributing to the industry's growth include the durability and low maintenance requirements of aluminum gates, their aesthetic appeal and customization options, the enhanced security they provide, and their sustainability due to aluminum's recyclability.

Competition in the industry involves major multinational companies, regional manufacturers, and specialized gate fabricators, offering a range of gate products and related services such as design, consultation and installation.

1.4 Project Objectives

The main objective of this project is to achieve an efficient integration of production and logistics operations within Company X. The specific goals of the project include a targeted 15% increase in productivity for the manufacturing unit and the logistics centre, as well as a reduction of the initial lead time from 5 weeks to 4 weeks.

These goals are based on opportunities identified during the observation of the current process. They have been carefully selected as achievable objectives that are expected to have significant positive impacts on the overall activity of Company X.

Figure 1.2 provides a visual representation of the goals, outlining the specific targets to be achieved. These targets are aligned with the identified opportunities for improvement and serve as important milestones for assessing the success of the project.

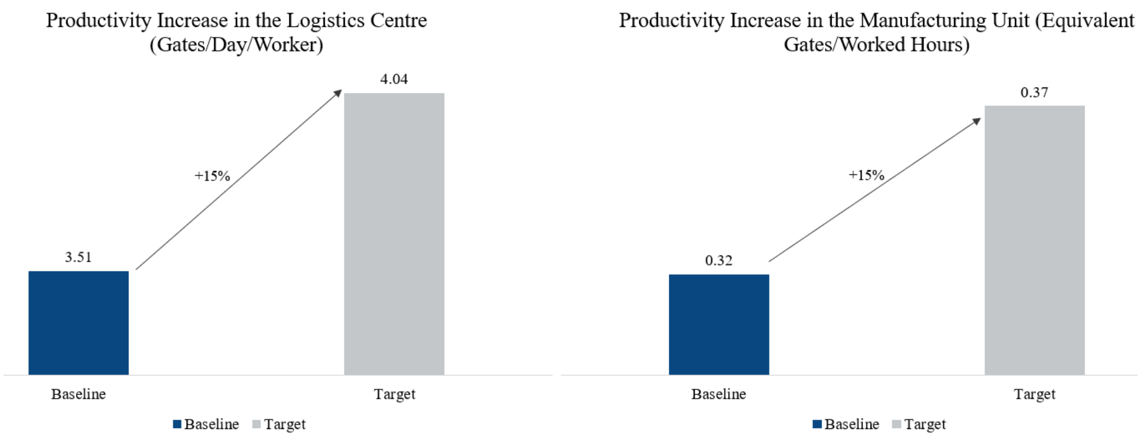

Figure 1.2: Productivity Increase in the Logistics Centre and Manufacturing Unit proposed for company X

1.5 Methodology

The methodology employed in this document is organized into three distinct phases. The initial phase involves the characterization of the existing processes (AS IS) and the definition and analysis of the key processes. Concurrently, a thorough examination of potential improvement opportunities is conducted.

Subsequently, the second phase entails the design of solutions based on the analysis of the initial state and the identified opportunities. During this phase, the proposed solutions are devised and formulated.

The third phase comprises the implementation of these solutions and monitoring the designated indicators to assess the impact of each implemented initiative on the identified performance metrics.

1.6 Dissertation structure

The remainder of this thesis is organized as follows. Chapter 2 focuses on the theoretical context, presenting the framework encompassing relevant concepts and methodologies that underpin the development of the dissertation.

In Chapter 3, the initial situation of the project is thoroughly examined. This chapter delves into the identification and description of the problem at hand, as well as an in-depth analysis of the existing production process and specific operations.

Chapter 4 outlines the proposed solutions for the identified problem and provides a comprehensive explanation of their implementation.

Chapter 5 presents the key findings and results derived from the implementation of the proposed solutions. This chapter highlights the impact and outcomes of the implemented strategies.

Finally, in Chapter 6, the main conclusions drawn from the project are presented. This chapter summarizes the achievements and insights gained from the work conducted. Moreover, it suggests future research directions and areas of focus for further development and improvement.

Chapter 2

Theoretical Background

In this chapter, the theoretical foundations which supported the project development are presented. The chapter is divided in the following subjects: The Role of Logistics Centres in Supply Chains, Warehouse Management Systems, Kaizen Principles, Kaizen Business System, Total Flow Management and Materials Management.

2.1 The Role of Logistics Centres in Supply Chains

2.1.1 Definition and Conceptualization

A logistics centre can be defined as a strategically located facility that consolidates and manages various logistics activities, including warehousing, inventory management, and order processing (Christopher, 1993). It works as the supply chain network's main centre for goods flow. Considerations for a logistics centre's conceptualization include its location, size, layout, integration of technology, and operational processes. The best layout and design for a logistics centre depends on various elements, including its accessibility to suppliers and customers, the availability of employees, economic considerations, and the particular requirements of the supply chain.

2.1.2 Functions and Operations

Supply chain management necessitates the establishment and efficient operation of logistics centres, which play a crucial role in facilitating the movement and coordination of goods throughout the supply chain. These logistics centres undertake a range of interconnected functions and operations, as illustrated in Figure 2.1, each contributing to the overall success of supply chain management.

The reception of goods is a critical process within logistics centres, involving the careful organization and storage of items delivered to the facility. These goods may come from various sources, such as suppliers, the company's own production unit, or earlier stages of the supply chain. Notably, the reception of goods represents a significant portion, approximately 10%, of the operational costs associated with warehouses (III and Hackman, 2019).

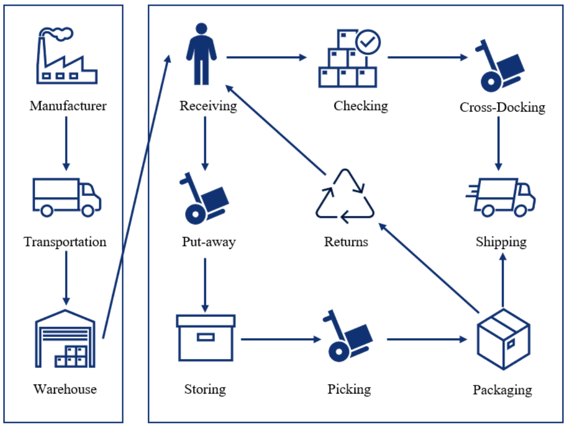

Figure 2.1: Logistics Centres Functions

Warehousing and inventory management are also vital functions performed by logistics centres. They serve as repositories for storing goods, ensuring proper inventory control, and managing stock replenishment. Effective inventory management is crucial for meeting customer demand in a timely manner and ensuring the smooth flow of goods throughout the supply chain (Racking, 2023).

Order processing and fulfillment are another key responsibility of logistics centres. They receive and process customer orders promptly and accurately, handling tasks such as picking, packing, and coordinating delivery with shipping partners. This streamlined process contributes to customer satisfaction and enhances overall supply chain performance (Racking, 2023).

Logistics centres may also offer value-added services to meet specific customer needs. These services can include product customisation, labeling, or kitting, providing additional benefits beyond warehousing and distribution. By offering these services, logistics centres meet unique customer requirements and enhance their competitive advantage (Group, 2022).

To optimize operational efficiency, logistics centres employ cross-docking and consolidation strategies. Cross-docking minimizes storage time by facilitating the direct transfer of goods from inbound to outbound transportation, reducing handling and storage costs. This strategy streamlines the flow of goods, enhancing efficiency and reducing lead times. Additionally, logistics centres consolidate orders to maximize transportation capacity and minimize costs, optimizing resources and reducing the environmental impact of transportation (Group, 2022).

2.1.3 Storage Locations Organization

There are two main strategies that are frequently discussed when it comes to organizing the storage locations within a logistics centre: chaotic and fixed positions (Mecalux, 2023).

2.1.3.1 Chaotic Positions

In chaotic positioning, the storage locations within a warehouse are not fixed, and items are stored in any available space without adhering to a predetermined order. When items are received, they are stored based on the available space at that moment. When an item needs to be picked, the system or warehouse staff locates and retrieves it accordingly (Mecalux, 2023).

One advantage provided by chaotic positioning is the flexibility it provides, allowing for dynamic allocation of storage space to efficiently manage variable inventory levels and product sizes (Mecalux, 2020).

Additionally, chaotic positioning improves accuracy by eliminating the need for strict segregation. Storing items adjacent to different products can enhance staff efficiency and reduce mix-ups. This approach enables items to be stored based on available space rather than predetermined locations. (Mecalux, 2020).

However, employing chaotic positioning also presents challenges that must be adressed. Longer retrieval times may be experienced as items can be stored in various locations within the facility. Proper organization of the inventory system is crucial to minimize retrieval time and effort (Mecalux, 2020).

Effective inventory tracking becomes paramount in chaotic positioning systems to prevent losses or misplacements. Robust inventory management practices, such as accurate records and real-time tracking, are essential to maintain control and visibility over stock levels.

To optimize the benefits of chaotic positioning, implementing a Warehouse Management System is imperative. A WMS streamlines inventory management processes and provides comprehensive tracking capabilities. Integrating a WMS into the chaotic position system enhances inventory accuracy, enables efficient retrieval operations, and ensures seamless coordination throughout the supply chain. Real-time inventory data and advanced tracking features offered by a WMS improve visibility, allowing warehouse staff to locate and retrieve items more efficiently while reducing the risk of misplaced or lost items.

2.1.3.2 Fixed Positions

Assigning precise and predefined placements for each item or product category within a warehouse is commonly referred to as fixed position storage. In this system, every item is allocated a designated storage space, where it remains until it is selected for transportation.

Fixed positioning offers a structured organizational framework for inventory management, contributing to improved accuracy and reduced instances of lost or misplaced products. The systematic arrangement of items enhances inventory control and overall operational efficiency within the warehouse. (Grit, 2021).

Furthermore, fixed positioning promotes labor efficiency by familiarizing warehouse personnel with the storage locations of items. This familiarity leads to faster and more efficient picking processes. Since items consistently remain in the same location, locating and retrieving them for order fulfillment becomes easier and quicker, ultimately saving time and increasing productivity.

However, fixed positioning also presents challenges. Limited flexibility is one such challenge, as adjustments to the storage layout may be required when stock levels or product dimensions change. Adapting to these variations can be cumbersome, as the system is less adaptable to accommodate such changes. Periodic reconfiguration of the storage layout may be necessary to optimize space utilization. (Grit, 2021).

Space constraints are another challenge associated with fixed positioning. Assigning specific positions to items may lead to inefficient space utilization when inventory levels fluctuate significantly. This can result in vacant slots or overfilled positions, compromising the efficient use of available storage space. Careful planning and continuous monitoring of inventory levels are essential to address space constraints and optimize storage capacity.

Logistics centres often adopt a hybrid strategy by combining both chaotic and fixed positioning systems. This approach provides greater flexibility and responsiveness to dynamic storage needs. Items with lower turnover rates or irregular sizes may be assigned chaotic positions, while those with high demand or fast turnover are allocated fixed positions. This hybrid strategy ensures effective inventory management while accommodating diverse storage requirements within the logistics centre (Grit, 2021).

2.1.4 Impact of Logistics Centres on Supply Chain Performance

Logistics centres play a pivotal role in supply chain management, offering a range of significant benefits. One such advantage is improved efficiency and cost reduction. By capitalizing on economies of scale and implementing effective order consolidation strategies, logistics centres optimize operational processes, enhance inventory management practices, and ultimately reduce transportation costs (Lambert and Cooper, 2000).

Furthermore, logistics centres contribute to enhanced customer service levels. By centralizing various supply chain processes and leveraging advanced technologies, these centres streamline order processing, leading to increased order accuracy and accelerated delivery times. This emphasis on efficiency and responsiveness ultimately fosters customer satisfaction and loyalty (Christopher, 1993).

In addition to customer-centric benefits, logistics centres also enable supply chain agility and responsiveness. Through efficient inventory management and strategically positioned facilities, logistics centres facilitate faster product availability, enabling companies to swiftly respond to shifting market demands. This agility provides a competitive edge and enhances overall supply chain performance (Gligor and Holcomb, 2012).

Collaboration and integration among supply chain partners are further facilitated by logistics centres. These centres serve as catalysts for improved coordination, visibility, and information sharing throughout the supply chain network. By bringing together diverse stakeholders and encouraging collaborative efforts, logistics centres foster closer relationships, enabling better synchronization and overall supply chain optimization (Christopher, 2011).

2.1.5 Challenges of Logistics Management for Custom Products

In the context of mass production, inventory and production decisions are primarily driven by sales forecasts. Conversely, in the realm of customised products, production is based on specific customer specifications. Consequently, maintaining low inventory levels is a key strategy in the customisation industry, necessitating the procurement of materials from suppliers in a nearly instantaneous manner. In mass production, inventory levels are typically replenished in the warehouse once materials drop below a predetermined safety stock threshold. Given that replenishment can be initiated before inventory depletion, the need for swift communication and distribution from suppliers becomes less critical compared to the customised products sector (Chandra and Grabis, 2004). The relationships between entities involved in both types of production are depicted in Figure A.1 and Figure A.2 in Appendix A.

In the mass production paradigm, once a product is finalized, it is transferred to a finished goods warehouse and awaits purchase orders for shipment. Conversely, in the customised products domain, where manufacturing occurs on a make-to-order (MTO) basis, the storage duration of finished products within the warehouse should be minimized, as each item is already designated for a specific end customer.

Extensive theoretical and empirical research conducted by scholars such as Verbraeck and Versteegt (2001), Cochran and Lewis (2002), Moser (2006), Biswas and Narahari (2004) have consistently highlighted the significant role of logistics as a dominant competency in the context of mass customisation and its' importance in the enhancement of supply chain processes.

Qiao et al. (2004) conducted a study that demonstrated the rationale behind segregating mass production and customised product strategies within companies, particularly in the context of total customisation where customer orders cannot be accurately predicted. This separation is exemplified by the National Bicycle Industrial Company (NBIC), which operates two distinct factories: one dedicated to mass production and the other to customised bicycles. Despite the customised bikes accounting for a mere 2% of total production, they contribute significantly to 27% of total revenues, underscoring the value attributed to customised products.

Furthermore, production lines must possess the flexibility to adapt and accommodate unforeseen customer demands. To exemplify this adaptability, the General Motors Michigan Electronic Vehicle assembly factory has implemented movable workbenches, enabling swift reconfiguration to meet new demands. This agile approach addresses the critical challenges associated with the production of customised products, namely the ability to reconfigure layouts and effectively manage logistics.

The concept of mass customisation, as identified by Jiao et al. (2003), necessitates a shift in production processes for organizations. In this context, logistics plays a crucial role in managing small quantities, highly personalised products, and variable demand rates while maintaining the desired service level.

Kim and Tang (1997) argue that reducing lead time and response time, combined with a shorter product development cycle, can lead to lower inventory levels, increased customer satisfaction, and improved strategic planning. To achieve these objectives, a methodology focused on eliminating non-value added activities and streamlining responsiveness within a lean/pull manufacturing framework must be employed.

2.1.6 Technology and Innovation in Logistics Centres

Companies are increasingly turning to technology and innovation to enhance their logistics centres, keeping pace with the expanding needs of the industry. Recent advancements in warehousing have introduced several crucial technologies and innovations.

One prominent technology is automation and robotics, which has gained significant adoption in the warehouse sector. Robotics technology allows for the automation of repetitive and physically demanding tasks, reducing labor costs, increasing worker accuracy, and enhancing overall production and efficiency. These robots can perform various warehouse tasks, improve safety conditions, and operate continuously, driving the growth of the warehouse automation market. In 2022, the market size for warehouse automation was valued at USD 19.88 billion, with a projected valuation of USD 54.60 billion by 2030, indicating a compound annual growth rate (CAGR) of 10.9% during this period. (Consulting, 2023).

Warehouse Management Systems also play a critical role in optimizing warehouse operations and meeting future customer demands, as will be further explained in the subsequent section of this chapter. As logistics centres continue to evolve, WMS will enable efficient inventory management and enhance overall operational performance.

Furthermore, the Internet of Things (IoT) has revolutionized logistical operations by connecting multiple devices and facilitating real-time data exchange. IoT sensors integrated into products, vehicles, and storage facilities provide valuable insights on inventory levels, location tracking, and condition monitoring. This real-time data enhances inventory management efficiency, enables proactive maintenance measures, and improves supply chain visibility. By connecting IoT devices, logistics processes can be coordinated and improved in real time (Kholodenko, 2022).

In addition to these advancements, notable developments in the fields of Machine Learning (ML) and Artificial Intelligence (AI) are transforming logistics centres. AI algorithms analyze vast amounts of data to identify patterns, forecast demand, and optimize inventory levels, leading to improved efficiency and cost reduction. ML models leverage previous data to enhance routing, scheduling, and warehouse layouts, optimizing resource allocation and reducing bottlenecks. AI-driven automation and robots enhance material handling processes, increasing efficiency and precision. Furthermore, AI and ML enable real-time tracking and monitoring of shipments, enhancing supply chain visibility. These technologies empower logistics centres to enhance efficiency, reduce costs, and improve customer satisfaction (Rana and Daultani, 2022).

2.2 Warehouse Management Systems

Warehouse management systems are software applications designed to support and optimize warehouse operations. It is primarily designed to handle the transportation and storage of commodities inside a warehouse, as well as the processing of related activities including shipping, receiving, put-away, and picking.

Its architecture is usually composed of a user interface that allows personnel to interact with the system, a database that serves as a central repository for storing relevant warehouse data, an integration middleware to facilitate communication and data exchange between the WMS and other external systems, such as Enterprise Resource Planning (ERP). In some cases, warehouse management systems may also be integrated with Warehouse Control Systems (WCS), which concentrate on the real-time optimization and management of material handling equipment, including conveyor systems, robotic arms, and Automated Guided Vehicles (AGVs) (Khan et al., 2022).

2.2.1 Key Functionalities

Companies increasingly recognize the significance of leveraging technology and innovation to enhance their logistics centres and meet industry demands. Warehouse management systems have emerged as a critical element for optimizing warehouse operations and addressing customer needs.

WMS encompasses essential functionalities that streamline warehouse operations and improve efficiency. Implementing an effective WMS offers benefits in inventory management, order processing, receiving and put-away, warehouse layout optimization, pick and pack processes, quality control, returns management, and reporting and analytics. (Vinculum, 2020).

Inventory management is a primary WMS functionality providing real-time visibility and control over inventory. Accurate tracking of inventory levels, item locations, and movements enables efficient inventory management, precise stock counts, and automated replenishment processes.

Furthermore, seamless order management is facilitated by WMS, overseeing the entire order processing workflow. This includes order picking, packaging, and shipping, ensuring accurate and timely order fulfillment while minimizing errors.

To streamline the receiving process, the system records relevant information about incoming products, verifies quantities, and allocates suitable storage locations. By considering factors such as item characteristics, demand, and accessibility, WMS optimizes put-away processes, leading to improved warehouse organization.

Warehouse layout and slotting optimization are critical WMS functionalities. By designating specific locations based on factors such as velocity, size, and storage requirements, WMS maximizes warehouse space utilization and reduces travel time for product retrieval, enhancing overall productivity.

Additionally, WMS enhances the efficiency of pick and pack processes by determining the most effective routes and techniques for order fulfillment. Supporting various picking techniques like batch picking and zone picking minimizes travel time and maximizes efficiency. WMS also assists in packing processes, facilitating labeling and package selection.

Quality control is addressed through WMS, ensuring accuracy, condition, and compliance with predefined standards for incoming and outgoing products. This rigorous quality control process contributes to customer satisfaction and maintains product integrity.

Reverse logistics management is handled by WMS, managing processes related to returns, repairs, and replacements. By recording returned items and initiating inspections based on predefined rules or workflows, WMS ensures efficient management of reverse logistics.

Lastly, WMS offers robust reporting and analytics capabilities, providing valuable insights into warehouse operations. Through generated reports, companies gain visibility into critical metrics such as inventory levels, order fulfillment rates, and storage utilization. These insights enable data-driven decision-making, empowering companies to identify areas for improvement, optimize resource allocation, and make informed strategic decisions.

2.2.2 Benefits of WMS Implementation

In addition to the direct benefits provided by its functionalities, there are several indirect advantages that organizations can experience through a WMS implementation.

The real-time visibility into inventory locations, movements, and levels contributes to improved inventory accuracy, minimizes stockouts and excessive inventory, thereby reducing carrying costs and stockout-related expenses. Furthermore, the availability of up-to-date inventory data enhances the accuracy of demand forecasting, enabling organizations to optimize inventory levels and respond effectively to customer demands.

Through the optimization of order picking and packaging procedures, WMS enables a faster and more precise order fulfillment process. As a result, organizations can achieve greater customer satisfaction, shorter order cycle times, and increased order accuracy. By ensuring timely delivery and accurate order fulfillment, organizations can enhance their reputation and customer loyalty.

The automation and streamlined warehouse processes it provides enables more efficient task allocation and minimizes the need for manual data entry. This, in turn, boosts labor productivity by increasing throughput and reducing labor costs. With WMS optimizing workflow and eliminating repetitive manual tasks, warehouse personnel can focus on value-added activities, leading to improved overall efficiency.

2.2.3 Challenges and Implementation Considerations

The implementation of a Warehouse Management System entails various challenges and considerations that need to be carefully examined to ensure a successful implementation process.

One of the main challenges is the integration of the WMS with existing systems and technologies, such as Enterprise Resource Planning and Transportation Management System (TMS), which can be complex. Achieving data synchronization, system compatibility, and process alignment requires meticulous preparation and collaboration to ensure a seamless integration that avoids disruptions to existing operations.

Change management is another critical aspect to address when implementing a WMS. The introduction of a WMS involves changes in processes, roles, and responsibilities within the organization. To facilitate a smooth transition, effective change management strategies should be employed, including comprehensive training programs, well-defined communication plans, and active stakeholder participation. This helps employees adapt to new workflows and embrace the benefits offered by the WMS.

The selection of a suitable WMS should also be carefully considered. The chosen system should have the capability to accommodate future growth and expansion. It should be able to handle increasing transaction volumes and adapt to evolving business requirements. Assessing the scalability and customisation options of the WMS ensures that it can grow alongside the organization and support its long-term objectives.

Selecting the most appropriate warehouse management system can be a challenging task, considering the multitude of options available in the market. With over 300 distinct options to choose from, companies must carefully evaluate their specific needs and requirements. It is essential to conduct thorough market research and assess available solutions. If a suitable WMS is not found, organizations may need to explore the possibility of developing their own system tailored to their unique operational needs.

Scavarda et al. (2012) conducted a study on the implementation of a Warehouse Management System in a distribution centre of a company that handles a diverse range of products. Following the implementation of an Enterprise Resource Planning system, the subsequent implementation of the WMS aimed to achieve inventory reduction, enhance customer service levels through real-time stock visibility, and optimize the utilization of warehouse space. The implementation process encompassed seven key phases: data collection from the warehouse, identification of ERP interfaces for integration, parameterization of ERP modules interfacing with the WMS, integration testing of the parameterized system model, definition of user menus and profiles, establishment of required reports for each user, and documentation of the implemented work for future system understanding. Among these phases, data collection emerged as a critical stage since it serves as the foundation for system parameterization, emphasizing the importance of the involvement of domain experts in distribution centre operations. Another pivotal phase involved the identification and parameterization of modules essential for the seamless integration of the WMS with the ERP system, enabling the realization of the combined benefits of their integration. One significant concern throughout the implementation process was the identification of products that were improperly stored due to warehousing restrictions or being assigned to inappropriate locations.

2.3 Kaizen Principles

Kaizen, derived from the Japanese words "Kai" and "Zen," conveys the concept of continuous improvement and signifies a process of change for the better. This philosophy emphasizes the importance of ongoing and incremental transformations that involve both management and operators, impacting all areas of an organization. Initially, these improvements may be modest and gradual, but over time, they yield substantial results with minimal sustained effort (Imai, 1986). Collaboration among all individuals engaged in the processes is vital, and the methodology should adhere to the following guiding principles:

1. **Create Value for the Client** - This entails assessing the utility gained by the client from acquiring a product or service in relation to the price paid. The entire process should be customer-oriented, with resources directed towards operations that directly benefit the customer. Eliminating waste in the form of unnecessary tasks and activities is crucial to achieving this objective. Understanding the customer's interests and priorities is essential to better serve their needs and enhance the overall quality of the offering.

2. **Create Flow Efficiency** - This involves eliminating non-value-added operations, referred to as "*muda*" or waste in Japanese terminology. By eliminating these stages, the process lead time can be shortened, promoting productivity growth and reducing expenses associated with non-value-added activities (Ohno and Bodek, 1988).

3. ***Gemba* Efficiency** - The term "*Gemba*" refers to the actual location where work is performed and where value is created. The Kaizen methodology emphasizes the importance of making frequent visits to the field or work site. This practice recognizes that the best setting for problem identification and root cause analysis is the actual place where the work takes place.

4. **People Involvement** - It emphasizes the formation of work teams and aligning objectives with the company's overall strategy. Continuous improvement relies on the performance of individuals, who are considered the most valuable asset of a company. Rather than blaming individuals for mistakes, the focus is on identifying process flaws as the root cause (Imai, 2012) (Coimbra, 2009).

5. **Being Scientific and Transparent** - All conclusions and decisions should be based on scientific justifications, employing data-driven and logical reasoning. Transparent communication of information among stakeholders facilitates a comprehensive understanding of the current state of operations, enabling informed decision-making and improvement (Coimbra, 2009).

2.4 Kaizen Business System (KBS)

Kaizen Institute has developed the Kaizen Business System (KBS), a comprehensive management framework designed to lead organizations towards excellence and create sustainable value for clients, shareholders, and employees. As a fundamental aspect of the organization's knowledge model, the internal content derived from the Kaizen Institute played a pivotal role in providing valuable insights and information regarding the KBS, which have been incorporated into this research.

As seen on Figure 2.2, the KBS is supported by the pillars of Operational Excellence (Quality-Cost-Delivery, QCD) and Growth Excellence (G:Growth), which bring together a variety of tools to handle the issues unique to each area. The Growth pillar has a more strategic focus, involving the promotion of sales, marketing, innovation and development. On the other hand, the Operations pillar concentrates on the QCD dimensions, using different tools in order to increase quality and level of service, and lower costs. Amongst these tools are Total Flow Management (TFM), Total Quality Management (TQM), Total Service Management (TSM) and Total Productive Maintenance (TPM).

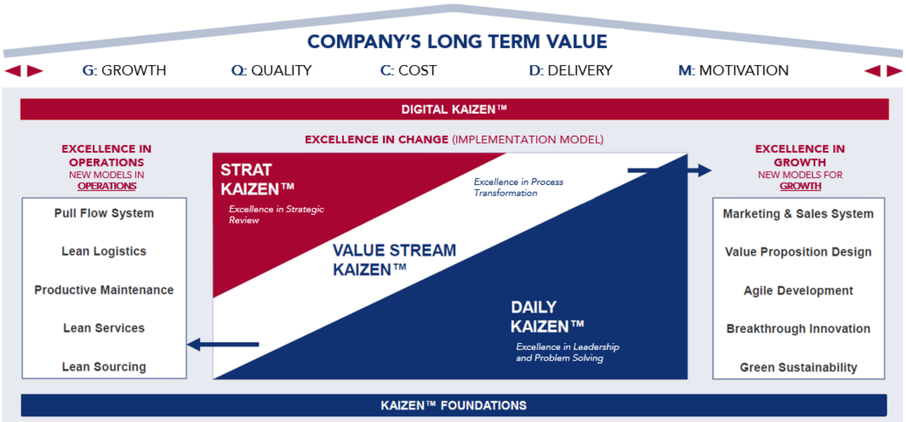

Figure 2.2: Kaizen Business System (Institute, 2023b)

The Kaizen Change Management, which is located in the centre and is represented by Kaizen Institute's logo, is a model that enables organizations to deploy and maintain the Kaizen methodology.

Finally, there is Digital Kaizen. This KBS component focuses on a collection of digital tools that help numerous initiatives take off and facilitate the implementation of the Kaizen methodology in organizations.

This model concentrates on the Growth, Quality, Cost, Delivery, and Motivation (GQCDM) objectives by acting on both the Growth and QCD components and utilising all the people in the organization. In this way, organizations can establish a culture of continuous improvement that promotes a sustainable long-term growth.

2.4.1 The 3 MU's

The Kaizen philosophy operates on the fundamental principle of waste reduction. Within this philosophy, waste is classified into three distinct categories, namely *Muda*, *Mura*, and *Muri*, each serving as a means to identify and address different forms of inefficiency.

Muda, which translates to "waste," encompasses activities that do not contribute value to the end client. These non-value-added tasks, be it unnecessary movements, excessive inventory, or redundant processes, are considered wasteful and should ideally be minimized or eliminated entirely.

On the other hand, *Mura* focuses on the concept of variability. It pertains to inconsistencies and irregularities within processes, operations, or outputs. These variations can lead to inefficiencies, bottlenecks, and quality issues. The goal of addressing *Mura* is to reduce variations, standardize processes, and create a stable and predictable workflow.

Lastly, *Muri* refers to overload, whether it be excessive strain on operators or machines. This type of waste occurs when tasks exceed the capacity or capabilities of individuals or equipment, leading to inefficiencies, errors, and potential safety concerns. *Muri* can occur when inexperienced operators are tasked with responsibilities that demand a high level of expertise or when machines are pushed beyond their designed limits.

2.4.2 The 7 *Muda*

Taiichi Ohno, renowned as the "father" of the Toyota Production System (TPS), emphasized the elimination of seven types of *muda*, crucial for achieving flow efficiency. Table 2.1 showcases an overview of the seven types of *muda*, along with examples highlighting their manifestation in the context of the manufacturing industry.

Table 2.1: Examples of *Muda* in Manufacturing

Muda	**Description**	**Examples of Manufacturing Wastes (Okpala, 2014)**
Overproduction	Leads to resource occupation, material consumption without financial return, and excessive inventory.	Producing sooner, faster or in greater quantities than customer demand.
People Waiting	Leads to wasted time and reduced productivity.	People waiting for a work cycle to be completed or waiting for the arrival of materials from suppliers.
Material and Information on Hold	Waiting for processing or delivery, it adds no value to the product and incurs costs that customers are unwilling to pay.	Excessive work-in-progress (WIP)
People Movement	Unnecessary movements contribute to inefficiencies and wasted effort.	Workers movement to reach necessary components for assembly.
Material Transportation and Information Transfer	Excessive transportation of materials and unnecessary information transfer.	Placing commonly used items in central locations instead of where they are used.
Over-processing	Non-value-added tasks that customers do not pay for.	Inspection, cleaning, and rework.
Errors and Defects	Products failing to meet quality standards result in additional costs, requiring reprocessing, extra work, and potential involvement of reverse logistics.	Scratches and using the wrong materials

2.4.2.1 VA/*Muda* Diagram

The VA vs *Muda* diagrams serve as a means of presenting observations made at the Gemba regarding operator activities. These observations typically involve monitoring operators for a limited time or until they complete a full cycle, documenting their activities and corresponding durations.

The subsequent step involves evaluating these tasks to classify them as value-added (VA) or wasteful (*Muda*), resulting in graphs such as Figure 2.3 . These diagrams highlight the inherent waste within the studied workstation, illustrating the percentage of tasks that contribute to value creation compared to unnecessary activities.

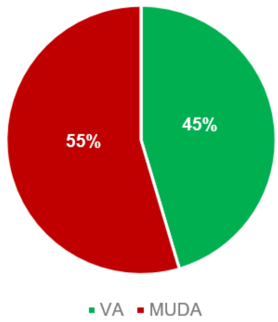

Figure 2.3: VA/*Muda* Diagram

2.5 Total Flow Management (TFM)

Within the Kaizen Business System, Total Flow Management emerges as a prominent methodology, aiming to establish a pull flow of information and material across the supply chain. This approach seeks to optimize the value chain by eliminating all types of *muda* and reducing lead times through the implementation of unitary flow and the principles of Just-In-Time (JIT).

In 1988, Taiichi Ohno challenged the prevailing mass production paradigm, which emphasized resource efficiency through large batch sizes and specialized groupings. Instead, Ohno proposed prioritizing customer needs and achieving flow efficiency. By reducing batch sizes and organizing work cells based on product type, Ohno aimed to optimize the flow of materials and information within the production system.

Ohno argued that inventory-driven approaches often mask underlying problems and inefficiencies. He emphasized the importance of addressing these issues rather than relying on excess inventory for uninterrupted production.

The Total Flow Management system, depicted in Figure 2.4, encompasses the production flow and external logistics pillars. These will be further detailed in subsequent subchapters, as they are integral to this dissertation's discussions.

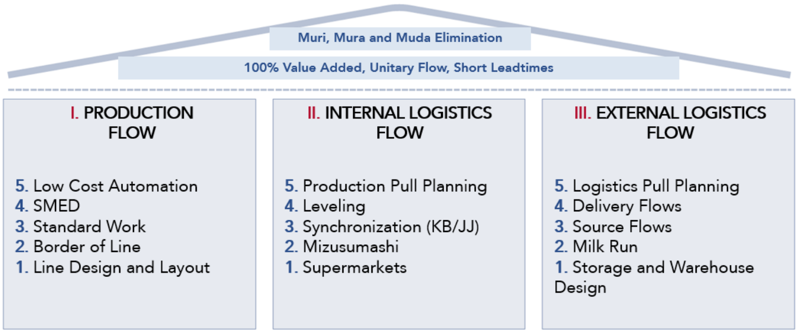

Figure 2.4: Total Flow Management system (Institute, 2023a)

2.5.1 Production Flow

The production flow improvement is supported by five methodologies, Line Design and Layout, Border of Line, Standard Work, SMED, and Low Cost Automation (Coimbra, 2013).

The four main goals intended to be achieved by their implementation are the creation of a one-piece flow, a high degree of flexibility of the supply chain, the elimination of all *muda*, and simplification before automation (Coimbra, 2013).

Within this chapter, a comprehensive examination of the Standard Work methodology will be presented, emphasizing its significance and relevance to the project undertaken in this dissertation.

2.5.1.1 Standard Work

Standard Work aims to establish an efficient flow of worker movements within one-piece flow cells and lines, ensuring high-quality and timely completion of tasks. It consists of established practices that must be consistently followed to achieve the best possible outcome.

Standard Work's key principals include:

- Consistency: Standard Work promotes a consistent approach to performing tasks or processes, regardless of the individual carrying out the work. This fosters overall quality, minimizes errors, and reduces process variability.

- Efficiency: It aims to remove waste and pointless steps from processes in order to achieve optimal use of resources, time, and effort. The most effective and efficient manner to complete a work must be carefully considered, documented, and improved over time through feedback and learning.

- Safety: Standard work ensures that work is carried out in a safe and compliant way by taking into account safety standards and best practices. This entails recognizing potential risks, implementing safety precautions, and giving staff members the appropriate training and oversight.

- Visual Management: Using techniques like standardized work instructions, task aids, and visual controls, standard work is frequently documented visually. Employee comprehension and adherence to defined standards are made simple for them by visual management, lowering misunderstanding and mistakes.

2.5.2 External Logistics Flow

The external logistics flow main targets are to minimize inventory, achieve a greater than 98 percent delivery in full, on time, and in specification (DIFOTIS), minimize logistics associated costs and eliminate all types of *muda* from the flow.

The traditional approach to supply chain management includes materials requirement planning based on push models, order forecasting for 80 percent of the production and only 20 percent of the production based on real orders, high levels of safety stock, major data reliability as information systems planning are based on forecasts and estimates (Coimbra, 2013).

Data reliability problems can be reduced by using standard operations and minimizing lead times. To achieve this, a physical flow of materials and information is created, and actual client orders and consumption are responded to.

The external logistics flow improvement is supported by five domains, Storage and Warehouse Design, Milk Run, Source Flows, Delivery Flows, and Logistics Pull Planning.

In the following sub section the Storage and Warehouse Design domain will be further looked into, as it is the only one within the project's scope.

2.5.2.1 Storage and Warehouse Design

The structuring of the spaces required to carry out the warehouse functions for the various types of warehouses is the subject of storage and warehouse design. The layout of these areas must allow a materials' flow. Determining the primary lines or groups of logistical activities and how to arrange operations and storage areas to meet those groupings are crucial for this aim (Coimbra, 2013).

Making products accessible to ultimate clients at a suitable delivery time is the warehouse's primary function. This delivery time, however, depends on the product and the market that it belongs to. Usually, shorter delivery times are seen as a competitive advantage and therefore, most companies are actively working towards trying to lower this value by synchronizing the available products in the warehouse with customers demand. Warehouses are most efficient when there is the least amount of inventory available while providing the best possible level of customer service.

This means that the flow warehouse will need to rapidly receive the incoming goods and bin them for storage, rapidly pick and send outgoing goods to customers in the appropriate packaging, and synchronize all material movements with customer needs to minimize the amount of goods waiting in storage inventory, as well as minimize all costs associated (Coimbra, 2013).

The traditional warehouse is characterized by people waiting, people moving from one place to another, too much transportation of material and too much material waiting to be handled. All of these are types of *muda*, which need to be minimized in order to achieve the warehouse's main goal which is to deliver the right material, at the right location, in the right quantity, with the correct presentation and efficiently (Coimbra, 2013).

2.6 Materials Management

Stocks are typically stored in warehouses and then consumed based on the company's requirements for production or to fulfil customer demands.

One paramount motive pertains to the establishment of safety stock. The inherent unpredictability of customer demand and the fluctuations in delivery times necessitate the presence of a buffer inventory. This safety stock acts as a protective measure, enabling organizations to address sudden surges in demand or delays in the replenishment process. By strategically determining the appropriate level of safety stock, organizations can strike a delicate balance between avoiding stockouts and mitigating the costs associated with holding excess inventory.

The time required for the materialization of operations and processes must also be taken into account. As organizations engage in various production activities, the transformation of raw materials into finished goods necessitates a certain duration. Consequently, work-in-process inventory emerges as an integral component within the production cycle. By strategically managing WIP inventory, organizations can optimize their operational efficiency and reduce bottlenecks.

Price fluctuations and misalignments between supply and demand introduce an element of uncertainty within the market. Organizations keen on maximizing their profitability and capitalizing on favorable market conditions may strategically hold inventory. By monitoring market trends and anticipating price fluctuations, they can position themselves to exploit potential opportunities. This strategic inventory management allows organizations to bridge gaps between supply and demand, ensuring product availability during times of scarcity or when prices are expected to rise.

In the pursuit of operational optimization, companies employ various planning and inventory methods when managing materials, depending on the types of parts or products involved. Particularly in make-to-order manufacturing environments, the primary objective is to achieve a harmonious equilibrium between on-hand raw materials and WIP inventory, ultimately ensuring satisfactory customer service.

To effectively manage materials in make-to-order manufacturing, companies must carefully align their inventory levels with customer demand. Unlike make-to-stock (MTS) manufacturing, where products are produced in advance and stored as finished goods, make-to-order manufacturing focuses on fulfilling customer orders based on specific requirements. This approach necessitates a flexible and responsive materials management strategy.

2.6.1 ABC Analysis

ABC analysis is a classification methodology used in materials management, whether raw materials or finished product, and that helps decision makers in the prioritization of references.

The ABC analysis follows the "80-20" rule from the Pareto principle, which states that there are a "critical few and trivial many".

This tool often bases its classification of items on annual turnover, as follows:

- A - Products that represent 80% of the turnover
- B - Products that share between 80% and 95% of the turnover
- C - Products that fall within the remaining 5% of turnover

The ABC analysis provides valuable insights into the uneven value distribution of inventories, emphasizing that a reduced number of items can represent a significant capital value, thereby exerting a substantial impact on inventory costs. Consequently, it is imperative to handle inventories differently, with a particular focus on ensuring higher service quality for A-references, characterized by shorter lead times and fewer stockouts. By prioritizing these critical inventory items, organizations can reap substantial financial benefits, as the impact of effective management interventions is amplified despite acting on a smaller number of references. This approach aims to establish inventory policies that allocate resources strategically, concentrating efforts on the few pivotal items rather than the numerous trivial ones.

While value-based measures are commonly employed in inventory segmentation, other criteria can be considered to classify each segment. Factors such as consumption quantity, service level, and demand demand can be taken into account. Once the criteria are chosen, break points are established to delineate the A, B, and C segments.

The ABC analysis offers several advantages, including the ability to analyze complex problems by focusing on essential factors, its applicability to diverse situations, and the visual presentation of results, aiding in comprehending inventory characteristics effectively.

It is imperative to recognize a fundamental limitation of the ABC analysis, which lies in its sole reliance on a single criterion for defining inventory segmentation. This restriction has prompted researchers to strive for enhancements to the methodology, aiming to increase the versatility and flexibility of this analytical tool. In order to expand the analysis and overcome this limitation, scholars such as Flores and Whybark (1987), Ernst and Cohen (1990), Saaty (1984), and Ramanathan (2006) have introduced alternative criteria for classifying inventories, thereby augmenting the classification process.

Chapter 3

Problem Characterization

In this chapter, the initial state of Manufacturing Unit 3 (MU3) and a comprehensive description of its functioning in conjunction with the logistics centres will be detailed, including an elucidation of the various types of products manufactured within the unit, along with an examination of their respective production processes. Additionally, the allocation and distribution of human resources within the manufacturing unit will be outlined, shedding light on the workforce composition and deployment. Moreover, crucial data gathered from the *Gemba*, a term referring to the actual workplace where value is created, will be presented and analysed.

Furthermore, this chapter will encompass a thorough evaluation of areas within the manufacturing unit and logistics centres that warrant improvement. By conducting a comprehensive analysis, deficiencies and inefficiencies can be identified, laying the foundation for subsequent corrective actions. Based on the insights gleaned from the *Gemba*, prioritization and decision-making regarding which areas to target initially will be conducted. This strategic approach ensures that the improvement efforts are focused and aligned with the overarching goals of the project.

3.1 Case Study

The initial situation encompassed three distinct manufacturing units, namely Unit 1 (MU1), Unit 2 (MU2), and Unit 3 (MU3), alongside four small distribution centres located in various regions of Portugal. As this chapter progresses, it will become evident that this initial configuration resulted in avoidable inefficiencies, as the product underwent excessive movement and transportation.

The original dispersion of operations was a strategic choice made by the company due to the limited availability of space to consolidate both manufacturing and logistics activities within a single location. However, as the company experienced growth over the years, the need for expanded space to accommodate both logistics and production became apparent. Consequently, the company made the decision to construct a larger facility and integrate manufacturing unit 3 with all the logistics operations from the three manufacturing units. This integration aimed not only to facilitate growth and eliminate unnecessary movement but also to align with market characteristics. The manufactured product faced significant seasonal fluctuations in demand, and with projected demand growth, the existing space was no longer sufficient. Furthermore, the integration offered the advantage of flexible workforce allocation, allowing for the seamless transfer of workers between the production unit and the logistics centre as needed.

This step also brought forth additional benefits as it allowed for the redefinition of the layout to enhance material flow and productivity, as well as the reduction of lead time by eliminating the transportation of finished products that occurred when the units were situated in separate locations.

Manufacturing Unit 3, which has been integrated with the logistics centre, specializes in the production of custom aluminium gates, distinguishing itself from both the local industrial sector and the company's competitors. The unique nature of this product requires the adoption of a MTO production strategy, whereby production is initiated based on received orders rather than stock accumulation. In contrast, the other two manufacturing units (MU1 and MU2) manufacture standard gates and, as explained in the subsequent chapter, employ a MTS strategy due to specific market characteristics.

This case study primarily focuses on the integration of Manufacturing Unit 3 with the logistics centre, which serves not only that particular unit but also the other two units within the group.

3.1.1 Manufacturing Unit 3 Products

The manufacturing unit under consideration specializes in the production of customized gates that are tailored to meet the specific requirements of individual customers. Consequently, its catalog comprises more than 300 distinct gate models, each offering a wide array of customisable attributes. This extensive range of attributes results in a diverse product mix. The following attributes can be customized for each gate:

1. Type of opening: Gates can be designed as either opening gates or sliding gates.

2. Opening direction: Sliding gates can open from either left to right or right to left, while opening gates can be configured to open inward or outward.

3. Number of sheets: Gates can be constructed with either one or two sheets, which are the gate structure.

4. Filling orientation and dimensions: The fill of the gate can assume different directions, such as horizontal, vertical, or diagonal, and have different dimensions. It is also possible to customise the filling type, which can consist in different profiles.

5. Dimension: Gates can be customized to different lengths and widths

6. Color: The company offers two types of colors for gates. Firstly, there are the standard colors that are readily available from suppliers and kept in stock. Secondly, there are personalized colors, which require a separate lacquering process in another industrial unit of the company to achieve the desired color.

As depicted in Figure 3.1, gates primarily consist of crossbars, plumbs, filling (often in the form of strips), and additional complementary profiles such as rails. Each gate is assigned a unique kit number that serves as its identifier throughout the production process. A kit encompasses all the necessary parts and components required for the fabrication of a specific gate.

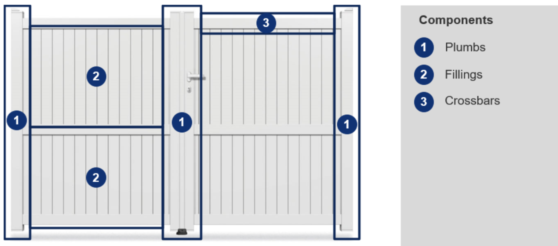

Figure 3.1: Aluminium Gate Constitution

3.1.2 Materials Flow

In comparison to mass production, the high level of customization inherent in this manufacturing unit introduces distinct variations in the production process of the gates. However, despite these differences, most pass through similar production sectors, albeit with variations in the specific operations conducted for each gate.

To gain a comprehensive understanding of the processes preceding the completion of gates, a materials flow mapping exercise was conducted. The mapping is presented in Figure B.1 in Appendix B. The analysis begins with an examination of the transformation undergone by each component of the gate, followed by a detailed exploration of the various sections where these processes occur.

Upon analysing the materials flow mapping, it becomes evident that several processes are shared among the various gate components. The journey of these components begins in the Raw Materials Warehouse, where they are initially stored. Subsequently, they are transported via carts to the corresponding buffer area associated with the first section of the production process. Once in the buffer, the components are fed into cutting machines, where they are shaped according to predetermined specifications based on the required component type.

Following the cutting process, the components are transferred to another buffer, awaiting completion of inspections in the preceding section, except for the crossbars, which do not require inspection and move forward to the buffer prior to the logistics park. The other components, upon successful inspection are also transported using carts to the same buffer. Within this buffer, these components remain until all the necessary elements for gate assembly are gathered. It should be noted that plumbs and certain complementary profiles undergo an additional process called machining. This process involves the use of hydraulic presses to punch the profiles, with some profiles potentially requiring further processing using a CNC machine. These machines are typically employed when standard punches are not available to meet specific requirements. Subsequently, the plumbs join the other profiles in the buffer area.

Once the cart has gathered all the required parts for the desired gate, the assembly of the accessories box commences. This box serves as a repository for all the complementary add-ons that buyers will utilize to assemble the gate in their respective homes. Simultaneously, the tops, which will be embedded on the ends of the plumbs, undergo preparation and are assembled with a ring. Following these operations, the logistics park operator transports the cart, complete with all the necessary components, to a buffer area where it awaits further processing on the assembly lines.

Upon reaching the assembly lines, the initial step involves placing the tops into the plumbs and constructing the gate's structure. Subsequently, the filling material is inserted, and the remaining components of the gate are assembled accordingly. Before proceeding with the packaging stage, the gate must undergo thorough cleaning on both sides to ensure its pristine condition. Only after this cleaning process can the gate be prepared for packaging. This entails placing sponge material on the corners of the gate and subsequently wrapping it with a protective plastic sleeve and cardboard cover.

3.1.3 Production Process

3.1.3.1 Cutting Sector

The first section in which the gate components undergo transformation is the cutting sector, which comprises seven cutting machines, each operated by two workers.

The materials required for the machines are delivered by means of an overhead bridge crane, which positions the transported materials in close proximity to the respective machines. Prior to initiating the cutting process, the workers manually load the material batches into the machines.

Following the loading phase, the machines are adjusted to accommodate the specific length of the profile typology. Each machine is dedicated to a particular profile typology, and their distribution among the seven machines is as follows: one machine is designated for crossbars, another for plumbs, reinforcements, and pipes, one for 45º cut strips, one for 90º cut strips, one for parquets and rails, one for special gates, and one for replacements.

Once the cutting process is completed, the cut profiles are transferred to a cart, which is subsequently moved to a buffer area for inspection. Furthermore, the tips of the initial material that have been cut and are no longer required are collected and stored in a separate container.

An analysis of these operations allowed for the determination of the value-added and non-value-added aspects within the section. Prior to this analysis, several improvement opportunities were identified.

In summary, five primary activities were observed within the sector: cutting the profiles, opening the batches, preparing the cart, storing the cut tips, and transporting the profiles. Among these activities, only the cutting of profiles operation is classified as value-added, as it directly transforms the product.

Based on time measurements of these activities, as presented in Figure 3.2, it was determined that 46% of the available worker time was allocated to non-value-added activities (*muda*). Building upon this initial analysis, further investigations were conducted to identify the most significant non-value-added operations. According to the graph, two of the four operations accounted for 77% of the total non-value-added time: opening the batches (41%) and initial cart preparation (36%).

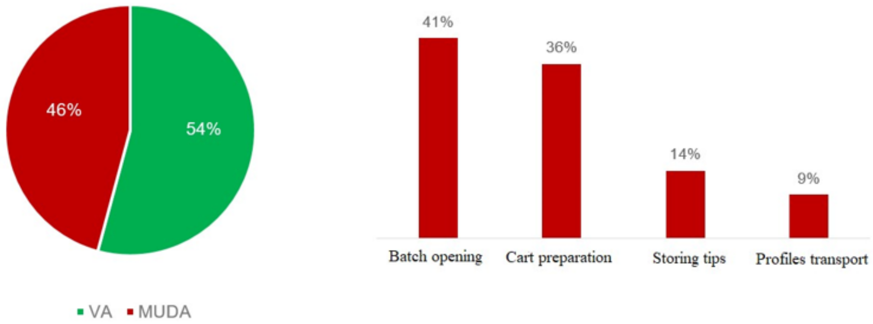

Figure 3.2: VA/*MUDA* Analysis of the Cutting Sector

Lastly, the following improvement opportunities were identified within the sector:

- Inspection and detection of defects currently occur after the cutting process, which means that materials may undergo value-added transformation only to remain unused.
- If any non-conformities are identified in the inspection sector, it will require the cutting sector to reconfigure the machine for cutting the same profile once again, leading to additional setup operations.
- Each workstation executes similar tasks in different ways, resulting in considerable variability between workstations.

3.1.3.2 Inspection Sector

Following the completion of the cutting process, the strips and plumbs advance to the inspection sector, where their condition is carefully evaluated, and any potential defects are identified. Within this sector, three distinct workbenches are allocated for the inspection tasks. The first workbench accommodates two workers responsible for inspecting strips with a 90º cutting angle, while the second workbench is attended by two workers tasked with examining strips with a 45º cutting angle. Finally, the third workbench is staffed by two individuals who perform inspections on the plumbs.

Since the aluminium profiles are initially wrapped in a protective plastic film during the cutting process to prevent damage, the inspection process begins with the removal of the film and subsequent cleaning of the profiles. The length of the profiles and the presence of defects are then examined based on the information provided in the manufacturing specification sheet. If any non-conformities are identified, the quality department is notified and tasked with investigating the source and cause of the defect.

Following the inspection, a new protective film is applied to the profiles, and a label indicating the kit number to which the profiles belong is affixed. The profiles are then loaded onto carts, with some carts being designated for internal logistics and others for machining processes.

An analysis of the non-value-added activities (*muda*) within this sector, as depicted in Figure 3.3, revealed that more than half of the workers' time (55%) was spent on non-value-added operations. Subsequently, efforts were made to identify the most significant non-value-added activities, and the results indicated that overprocessing accounted for over one third (37%) of all non-value-added operations, while packaging the profiles after inspection accounted for 32%.

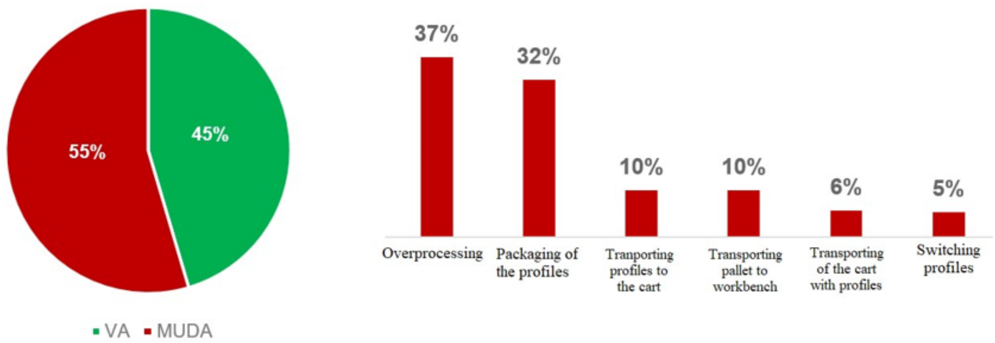

Figure 3.3: VA/*MUDA* Analysis of the Inspection Sector

The improvement opportunities identified within this sector are as follows:

- The identification of profiles involves a significant amount of time due to overprocessing. Therefore, reducing this type of *muda* can enhance productivity.
- The operations related to inspecting and identifying profiles are unbalanced, resulting in a high level of WIP. According to Little's Law (Little, 1961), which states that Lead Time equals WIP divided by Throughput, an unbalanced workload can lead to increased Lead Time, assuming a constant throughput.

3.1.3.3 Machining Sector

As mentioned earlier, certain profiles within the manufacturing process undergo machining procedures using hydraulic presses, and some may even require additional CNC machining. Following the inspection stage, the profiles that necessitate these operations are directed to the Machining Sector, where three punching cells are situated. Each cell consists of three hydraulic presses equipped with distinct matrices. These matrices are designed for various types of cuts, including those for the lock, gate stops, and fitting between profiles.

Furthermore, the sector comprises three CNC machines, each operated by a single worker. As previously stated, some profiles may not conform to the matrices used in the hydraulic presses or possess unique requirements, thereby necessitating CNC machining.

Once these machining processes are completed, the profiles are placed on carts and made ready for internal logistics.

The analysis of value-added and non-value-added activities (VA/*MUDA*) conducted within this sector, along with the allocation of time to non-value-added activities, and the identified opportunities for improvement can be found in Appendix C.

3.1.3.4 Logistics Park

The logistics park serves as the central location for gathering and storing the elements of the kits, which are later transferred to the assembly lines. It encompasses two stations: the opening gates logistics park and the sliding gates logistics park. The opening gates components are consolidated in the first station, while the sliding gates components are gathered in the second.

Within this section, the workers are responsible for collecting and assembling the profiles from the inspection and machining sectors. These profiles are stored in the parking lots alongside their respective manufacturing specification sheets. Once a complete kit for gate manufacturing has been assembled with all the necessary profiles, the worker in charge of the parking lot schedules its entry into the assembly line and places it in the corresponding queue.

Typically, internal logistics operations concentrate a significant portion of non-value-added activities (*muda*) to enable production to focus on creating value for the customer. Consequently, these sections often exhibit a substantial amount of time dedicated to non-value-added operations. This observation is supported by the findings obtained through the analysis of *muda* activities, as illustrated in Figure D.1 in Appendix D, where the identified opportunities for improvement are also documented.

3.1.3.5 Assembly Lines

The assembly section consists in three lines used for different types of gates and have different characteristics, as presented in Table 3.1.

Table 3.1: Assembly Lines Characteristics

Line	**Types of Gates produced**	**Process**
1	Opening Gates	Each employee has a fixed station and the gate moves along the line.
2	Special Gates	Only one employee is responsible for the entire gate assembly process. These gates have a high complexity degree and require more time to be assembled and therefore, could lead to the obstruction of the production flow in the other assembly lines.
3	Sliding Gates	Each employee has a fixed station and the gate moves along the line.

The first step in this sector is to place the tops on the extremities of the plumbs. Then, the gate structure is assembled and the filling is placed in it. The next step depends on the type of gate but usually, following the filling placement, a lock is screwed to the gate. Finally, it is cleaned and packaged.

The shipping note is applied on the gate after assembly and packaging is finished, and a tablet reads the note's code to signal the internal software that the gate has left production and is prepared to be delivered to the logistics centre. The gates are packed onto pallets and organized according to the production sequence.

The VA/*MUDA* analysis performed on this sector, the identification of how much time is spent on non-value added activities, and the improvement opportunities found can be observed in Appendix E.

3.1.4 Logistics Centres Organization

Upon departure from the manufacturing units, the gates undergo transportation to designated logistics centres for subsequent processing. The company operates a network of four small-scale logistics centres that serve as hubs where the gates are received, managed, and prepared for their next stages of distribution.

Upon arrival at the logistics centre, where gates are typically received on a daily basis, a team of two workers is assigned to handle the receipt and put-away operations due to gates' weight and dimensions. The gates are received in pallets and must be carefully taken out and stored by final customer. The company works with productive weeks, which means that with this allocation of gates per client, gates to be dispatched in different weeks may be mixed on the same pallet.

Every week, the workers in the logistics centre are provided with a paper document containing a comprehensive list of orders that need to be fulfilled. This document specifies the required kits associated with each order. The standard kits are organized in the warehouse by client, meaning that every time an order needs to be fulfilled, the workers must go to the clients designated location and then look for the kit among all the others. In addition to this, when it comes to customised gates, the absence of location information presents a significant challenge, resulting in considerable time wastage while searching for the corresponding kits.

Besides the time wasted in searching for the location of the kits, another issue arises from the fact production planning aims to reduce waste, which means kits to be dispatched in different weeks are often produced sequentially. This mixing of kits leads to further inefficiencies as workers must spend a significant amount of time maneuvering gates to access the intended one. In some instances, the intended gate may be positioned at the back of the pallet, requiring the removal of approximately six to seven gates just to reach the desired gate. Such unnecessary movements and manipulations of gates not only consume time but also introduce the risk of potential damage or errors during the process.

Following the picking process, the next operation involves packaging the collected kits. Each kit is carefully arranged on a pallet and secured with duct tape to ensure safe transportation.

It is important to note that the shipment of the gates is facilitated by a Second Party Logistics (2PL) provider. Consequently, the product is considered complete within the logistics centre once the truck is loaded with the respective gates.

After conducting careful observations and comprehensive analyses of the existing operational processes within the logistics centre, several improvement opportunities have emerged. These opportunities have the potential to enhance efficiency and productivity, ultimately leading to improved overall performance.

Firstly, a significant amount of time is currently being wasted during the picking process. Workers encounter challenges when attempting to locate the specific kit required for order fulfillment. Despite the existence of designated locations for standard gates clients, the workers still face difficulties in locating these assigned positions as there is no visible identification in the warehouse. This inefficiency in the picking process hampers productivity and can result in delays in meeting customer demands.

Secondly, a duplication of tasks has been identified between the manufacturing unit and the logistics centre. Within the MU, kits are diligently placed on pallets, only to be transported to the logistics centre where they are subsequently removed from the pallets and stored. This redundant handling of kits not only consumes additional time but also introduces unnecessary complexities and potential errors. Streamlining and optimizing this process can significantly improve operational efficiency.

Lastly, the current storage allocation practices in the logistics centre hinder the effective utilization of available space. The fixed storage locations assigned to specific clients restrict the flexibility and adaptability of the storage layout. This rigidity in storage allocation leads to an inefficient use of the valuable storage capacity within the centre. Even during periods when a client's order volume is lower than usual and stock levels are reduced, the designated space assigned to that particular client remains unused. This underutilization of storage space represents a missed opportunity for optimizing the overall space utilization within the logistics centre.

Addressing these identified improvement opportunities has the potential to enhance the operational processes within the logistics centre. By streamlining the picking process, eliminating redundant tasks, and adopting a more flexible storage allocation strategy, the centre can achieve higher levels of efficiency, productivity, and utilization of resources. These improvements will contribute to the overall effectiveness of the logistics operations and ultimately result in enhanced customer satisfaction and profitability.

3.2 Relevant Data to the Study of the Production Process and Logistics Centre

The gathering and analysis of data pertaining to Company X's production process is of paramount importance. This approach aligns with the philosophy advocated by Williams Deming, emphasizing that without measurement, control is unattainable, and without definition, measurement is impossible (Berenson, 2016).

3.2.1 Cutting and Inspection Sector Data

In order to gain a deeper understanding of the production process, a detailed analysis was conducted on the materials flow specifically from the cutting sector to the inspection sector. The analysis was made to the strips with cutting angles of 45º and 90º, and plumbs as these are the profiles that require inspection. These flows are presented in Fig 3.4.

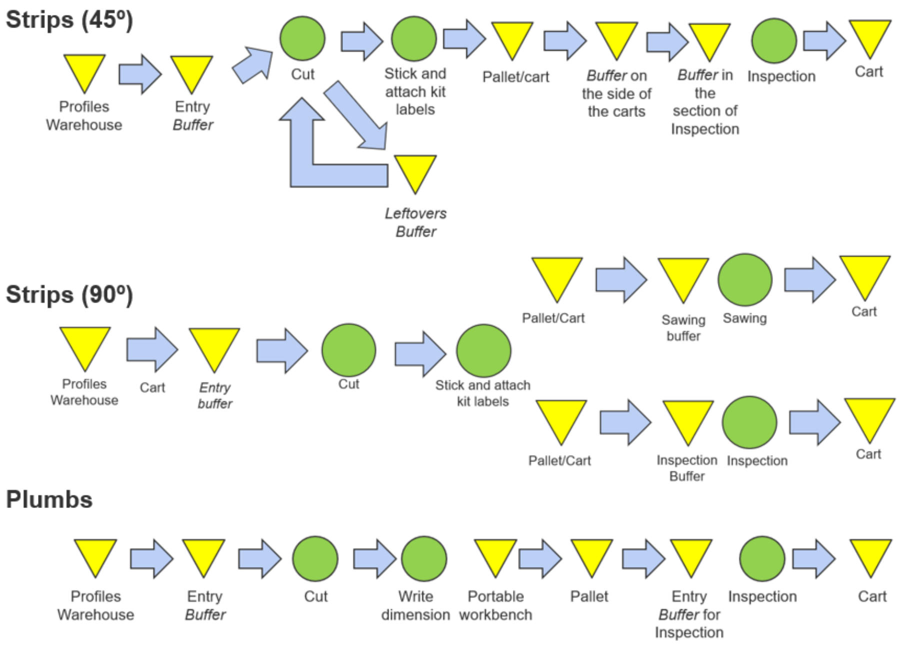

Figure 3.4: Materials Flow from Cutting Sector to Inspection

Through the analysis of these workflows, it becomes evident that a significant number of material movements are involved, often repetitive in nature. Such organizational practices contribute to time wastage, particularly when it comes to locating carts, a common occurrence in the inspection sector where inspectors have to search for the next cart to be inspected. Furthermore, various instances of overprocessing operations were identified, including the task of manually documenting the dimensions of the plumbs and attaching kit labels.

Another notable observation was the primary responsibility assigned to the second cutter, primarily revolving around helping the other cutter picking up the batch and supplying the cutting machine. This particular role falls under the category of non-value-added operations, adding limited or no direct value to the overall production process.

3.2.2 Key Performance Indicators

To effectively monitor the project's progress and assess its status, several Key Performance Indicators (KPIs) have been established. The primary KPIs revolve around the productivity of both the manufacturing unit and the logistics centre. Additionally, the lead time was analysed and utilized as an indicator of performance.

3.2.2.1 Productivity in the Manufacturing Unit and Logistics Centre

Evaluating the productivity of the manufacturing unit solely based on the absolute number of gates produced can be misleading, given the custom nature of the gate production process. Each gate manufactured in this facility is unique, presenting varying degrees of production complexity. Consequently, it was essential to create clusters of gate models according to their typology and assign them specific complexity ratings. These assigned complexity ratings can be seen in Figure F.1 in Appendix F.

To derive a more meaningful measure of productivity, the complexity degree assigned to each gate model is multiplied by the absolute quantity of gates produced, resulting in an equivalent number of sheets. This choice was made because certain gates consist of two sheets, while others are composed of only one. As a result, producing the same gate model with two sheets takes nearly twice as long as producing it with only one sheet. Based on historical productivity data gathered the initial baseline value stood at 0.32 equivalent gates per worked hour. With the aim of achieving a 15% increase in productivity, a target value of 0.37 equivalent gates per hour worked was subsequently established.

Regarding the logistics centre, historical data on shipped gates was utilized to calculate past productivity values. The average productivity rate of 3.51 gates per day per worker was established as the project's baseline. The objective is to achieve a 15% increase in productivity, aiming for a target of 4.04 gates per day per worker.

3.2.2.2 Lead Time

Manufacturing Unit 3 operates on a production week basis, with an average lead time of 5 weeks communicated to clients. The workflow is divided into distinct stages, each corresponding to a specific week.

The first week is dedicated to order reception and processing. During this period, incoming orders are received and reviewed, ensuring accuracy and completeness. Any necessary clarifications or modifications are addressed at this stage.

The second and third weeks are primarily focused on generating production sheets and material lists. These documents outline the required materials and components for each order. Raw material orders are placed during this period to ensure timely availability. Additionally, production planning activities are undertaken, ensuring that resources are allocated efficiently and production schedules are established.

The fourth week marks the initiation of production activities. This is when the actual manufacturing processes commence, utilizing the materials and components gathered in the preceding weeks. Assembly, fabrication, and quality control activities take place during this phase to ensure adherence to product specifications and standards.

The final week corresponds to the dispatch week. It encompasses activities related to packaging, labeling, preparing the finished products for shipment, and ensuring they are properly secured and documented.

Chapter 4

Solutions Design and Implementation

4.1 Logistics Centre Layout Design

The first step in moving the manufacturing unit and the logistics operations related to this unit and the two other units of the group was to understand how the available space would be allocated.

To design the layout, it was therefore important to look at the company's stock history regarding each manufacturing unit, and thus obtain the area occupied each month. Due to the seasonality of the market, a period from January 2021 to March 2022 was analysed, in order to obtain a complete cycle with visibility on the seasons of highest and lowest demand, as presented on Figure 4.1.

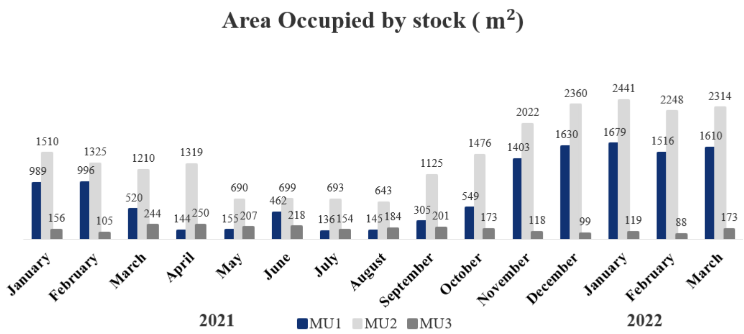

Figure 4.1: Historical data of the area occupied by stock per Manufacturing Unit

For manufacturing units 1 and 2, demand reaches maximum values from April to August. This demand value is higher than the production capacity of the units and in the rest of the year the situation is reversed and the production capacity is higher than demand. Thus, these two units opt for an MTS strategy to be able to meet demand in the months when it is higher. As a consequence, the months prior to peak demand are also the months in which there is a greater amount of stock and therefore a larger occupied area. As can be seen in the graph, for manufacturing units 1 and 2, the maximum values of occupied area by stock were reached in January 2022.

For manufacturing unit 3, due to the MTO strategy derived from the nature of the product, the values of occupied area per stock are much lower than in the other units, since, after production, the kit is dispatched on the same day or in the following days. In this unit demand also increases in the months of April to September, so it is expected that the stock at that time also increases due to the MTO production strategy, as confirmed by the graph.

Based on the values of orders per customer and the number of shipments per week for each, the stock coverage was calculated, which should be the value necessary to cover the order, so if, for example, a customer has one dispatch per destination per week, this means that there will be enough stock in the warehouse to ship the to customer on the fifth day. So, according to the average daily production value destined for each customer, the maximum number of kits that will be stored for each customer was calculated. Based on the average value of 10 kits per pallet, the number of pallets in stock needed per customer was obtained, as presented in Figure 4.2.

Clients	% Orders Volume	Number of dispatches/week	Number of dispatches per destination	Stock coverage (days)	Daily production (kits)	Max. Kits in Stock	Number of kits/pallet	Number of pallets in stock
A	55%	18	3.0	1.7	119	238	10	24
B	15%	3	2.4	2.1	32	81	10	8
C	10%	2	1.2	4.2	22	108	10	11
Others	20%	2	1.2	4.2	43	216	10	22

Figure 4.2: Analysis of the number of necessary pallets for Manufacturing Unit 3

With these levels, the value of 65 pallets in stock was reached. However, when doing this dimensioning, it is necessary to take into account the future growth objectives of the company for this manufacturing unit, which is 20% over the next 5 years. Taking this into account, the value for which the dimensioning will be done in this unit is 78 pallets (65 pallets * 1.2).

Having the total number of pallets, it was then necessary to understand the space occupied by each pallet. There are two different pallet sizes: 5.6 and 2.1 metres long. On average, in the same period under analysis, one third of the gates produced were stored on 5.6 metre pallets and two thirds on 2.1 metre ones. With these values, it is obtained that there are 26 pallets that occupy 5.6 metres each, and 52 pallets that occupy 2.1 metres each, totalling 254.8 metres. Since each aisle is 53 metres long, it is then necessary a total of 5 aisles.

For the despicking cells, which are going to be explained further in the next section, a 9 metre wide corridor is required. This gives operators enough space to handle the carts, even with the larger gates.

Upon completion of the calculations, a comprehensive layout for the logistics centre was derived for the stock of manufacturing unit 3. This layout comprises five stock aisles positioned on the right side of two despicking cells, which serve as the interface between production operations, situated on the left side of these cells, and logistics activities.

For Manufacturing Units 1 and 2, as the strategy is MTS production, the highest stock values presented in Figure 4.1 were taken into consideration for the calculation of the necessary area. Manufacturing unit 1 has 36 different references of products and has reached a peak of occupied area in January 2022 with 1679 square meters, whereas manufacturing unit 2 has a more diverse portfolio, constituted by 151 references, and reached it stock peak occupancy also in January 2022, with 2441 square meters. Based on the stock values of the gates in January 2022, the required space for each gate model in the two units was calculated, taking into account the dimensions of the pallets (which vary in size) and the number of gates per pallet. This calculation provided the occupied area per gate model, which was then used for the ABC classification.

To accommodate the different gate sizes and optimize the flow of goods, specific aisle widths were established. Aisles with a width of 7 meters were designated for handling larger gates with pallets longer than 2.1 meters, allowing sufficient space for maneuvering and ensuring safe and efficient movement. Narrower aisles measuring 4 meters in width were assigned for smaller pallets, providing a suitable environment for their handling.

There are five corridors for stock allocation:

1. One corridor dedicated to SKUs A for gates with pallets longer than 2.1 meters (located on the right side of the 7-meter aisle). It contains 37 stock positions with 27 meters length.

2. One corridor for B SKUs with pallets longer than 2.1 meters (located on the left side of the 7-meter aisle). It contains 33 stock positions with 14.45 meters length.

3. One corridor for A SKUs with pallets shorter than 2.1 meters (located on the left side of the 4-meter aisle). It contains 56 stock positions with 25.3 meters length.

4. One corridor for B SKUs with pallets shorter than 2.1 meters (located on the right side of the 4-meter aisle). It contains 44 stock positions with 13 meters length.

5. One separate area reserved for C SKUs. This area allows access to the pallets from two different sides, enabling each aisle to accommodate two references of gates and making optimal use of the available space. It contains 18 stock positions with 17 meters length. Therefore, as there can be 2 references in each corridor, it is possible to store 36 references in this area.

It is worth noting that gates with pallets larger than 2.1 meters cannot be positioned next to the 4-meter aisle due to handling limitations, whereas gates with pallets smaller than 2.1 meters can be placed next to the 7-meter aisle as they only require 4 meters of space for handling.

Considering the 2.1-meter pallets as the ones with the most constraints, they were allocated first to their respective stock positions. Following the ABC classification, the A-reference gates were distributed throughout the A-reference corridor, filling it completely. Subsequently, the B-reference gates were allocated to their designated positions, resulting in 8 vacant positions.

Next, the gates with pallets smaller than 2.1 meters were addressed. Based on their ABC classification, the A SKUs were assigned to their respective stock aisle. As the A-reference corridor was insufficient, the A SKUs were placed at the beginning of the B corridor to be closer to the loading and unloading dock. Additionally, 6 of these A SKUs (occupying 8 positions) were placed in the B SKUs of pallets larger than 2.1 meters to optimize the remaining space. The B SKUs were then allocated to their respective corridor, leaving 9 empty positions.

Following that, the C references were allocated to their designated zone. Since there are 18 stock corridors with two access points, this zone can accommodate 36 SKUs. However, there are 63 C references, so the ones representing the largest stock area were selected to occupy the 9 vacant positions in the B-reference corridor. This leaves 54 references remaining for allocation. Out of these 54, 9 had zero stock value and were only placed in the reinforcement zone, which is a reserved zone for stock in each manufacturing unit. Consequently, due to limited space, the 9 C references with the smallest occupied area value were also placed in the reinforcement zone, resulting in 36 references remaining in zone C.

The allocation of the SKU's to each stock corridor can be observed in Figures G.1 in Appendix G.

4.2 Despicking Cell

As previously seen, one of the main tasks in the logistics centres was to put-away the received gates and store them by customer. Due to the random sequencing of the produced gates, this process, also known as despicking, led to multiple inefficiencies in the supply chain, such as duplication of tasks. One example is that the gates had to be stored in pallets in the production units, only to later be taken off the same pallets and organized by customer in the logistics centre.

With this in mind, after the integration of the manufacturing unit with the logistics centre in the same industrial unit, a Despicking Cell was designed. The main goal of this cell was that the arriving gates from production were already arranged by destination and therefore increased the productivity in the logistics centre, without causing any impact on production productivity.

The last production sector is the assembly lines, which consists of three lines, however, the second one is for special gates, which are very complex and the average production is around 8 per day. Therefore, it was decided to implement this cell only in lines 1 and 3, which had sufficient production values to justify the required space. The production of the special gates was then integrated in these cells and according to the type of the special gate it would go to the despicking cell from line 1 or 3.

As this is a business-to-business (B2B) company with fixed clients, it is possible to perform an ABC analysis on the number of gates sold per customer, for opening gates, in order to create a cell with fixed positions. It was decided to follow with absolute gate production values and not with sales volume due to the discrepancy in gate prices. If this reasoning had been followed, it would be possible to get customers associated with high sales volumes and having orders for few gates, and customers with lower sales volumes and more gates ordered. However, for the customer associated with a lower sales volume more gates were produced. The obtained results are present in Table 4.1.

Table 4.1: ABC Analysis for Opening Gates

	A	**B**	**C**
Number of Clients	3	4	3
% of Orders Volume	75.70%	19.33%	4.97%

As observed in the table, 75.70% of the orders volume is concentrated in 3 clients (Client A, B and C). These observations corroborate Pareto's Law, the foundation of this analysis, which estimates that 20% of stocks translate into 80% of the turnover. Confirmation of this law allows one to devote attention and effort to only 20% of the cases knowing that it will have a huge impact on 80% of the business volume. Once these solutions are built, it becomes possible to deal with the exceptions in another way since there is already the benefit of the main solution.

As a result, a layout of the Despicking Cell 1, as seen in Figure 4.3, was designed that is based on the following fundamentals:

- The cell is divided into carts of two types, those for production and those for logistics. The production carts are the location where the kits are placed after packaging at the end of the assembly line by the production operators, and the logistics carts are the ones that are moved by the logistics workers to the respective storage in the logistics centre.
- The carts for the 3 customers that represent the highest percentage of order volume are closest to the end of the assembly line. Since 75.70% of the production will be allocated to these, then in 75.70% of the produced kits there will be minimized travel.
- When a kit allocated to these three customers is produced, it is directly placed on the production cart of the respective customer. In this way, in 75.70% of the gates we are reducing the despicking time, since the gate already leaves production grouped by customer.
- For the remaining 7 customers, which represent 24.30% of the production, there is a production cart called "Others" where the respective kits are put. When this cart is full, the logistic operators distribute the kits from the cart to the logistic carts dedicated to the respective customers.
- One cart had to be reserved for the special opening gates from assembly line 2.
- The 2 cardboard carts must be placed near the assembly line since they are used for packaging of the kits.
- There must always be an empty cart in the designated place so that when the production carts are full, they can be taken and replaced directly by an empty one, in order to ensure that production does not stop for lack of cart to place the kits.

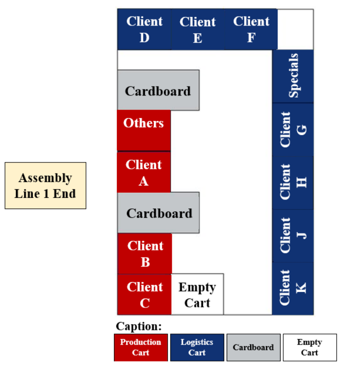

Figure 4.3: Assembly Line 1 Despicking Cell

In the case of Despicking Cell from assembly line 3, where the production volume is significantly lower compared to assembly line 1, with an average production of 35 kits per day as opposed to 115 kits in line 1, and considering a more evenly distributed distribution of orders across clients, another approach was established. It was determined that Cell 3 would operate with a single cart dedicated to production, designated as "LINE 3" in Figure 4.4. When full, this cart is moved by the logistics operators to the second reserved space for production carts, in the centre of the cell, and awaits there until the operators place a new empty cart on the place they originally took this cart from ("LINE 3" cell). The logistics operators would then distribute each kit to the respective carts assigned to each client.

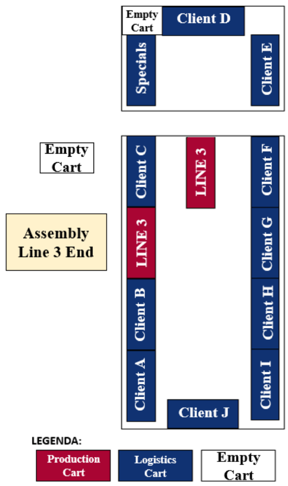

Figure 4.4: Assembly Line 3 Despicking Cell

The introduction of these cells brings forth several benefits, including enhanced efficiency in both the storage and picking processes within the warehouse. By segregating the gates based on the respective customers, the storage process becomes more streamlined. Additionally, the organization of gates according to the expedition week further optimizes the picking process. Consequently, the time spent maneuvering gates to access a specific one on the storage pallet is significantly reduced.

4.3 Warehouse Management System

Following the layout design of the logistics centre, a crucial decision was made regarding the storage positions for manufacturing unit 3. It was determined that a chaotic storage approach should be adopted due to the inherent diversity of the produced gates, rendering the fixation of storage positions based on gate type impractical. Chaotic storage offers advantages in terms of optimal space utilization, however, it requires meticulous inventory organization. Without a robust inventory tracking system, significant time wastage can occur when searching for specific kits to be shipped. This is precisely where the implementation of the Warehouse Management System

(WMS) assumes significance, as it enables efficient inventory management and real-time tracking of the location of each kit.

Consequently, with the aid of the WMS, logistics operators are equipped with the ability to precisely identify the whereabouts of each kit at any given moment. This functionality proves invaluable at the start of each day when dispatch orders are received, which subsequently need to be prepared throughout the day. With knowledge of the precise location of every kit within an order, logistics operators can streamline their operations, ensuring timely and accurate fulfillment of customer requirements. The main phases required for this implementation can be seen in Figure 4.5.

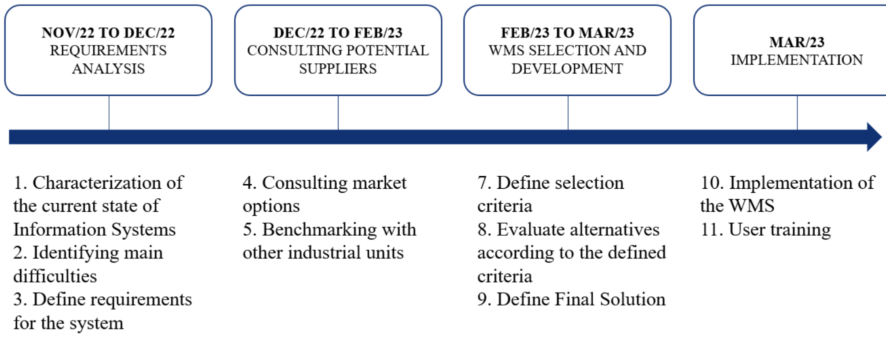

Figure 4.5: WMS Implementation Steps

The initial step in the implementation of the Warehouse Management System (WMS) involved the comprehensive characterization of the company's existing Information Systems. Presently, the company exclusively operates with a management software and has yet to adopt an Enterprise Resource Planning (ERP) system, although such implementation is anticipated in the future.

Subsequently, the primary challenges were assessed. Notably, one of the significant hurdles encountered during this implementation pertains to the integration with the company's internal management software. Since this system is custom-built by the company, acquiring a standard WMS solution could pose difficulties in achieving seamless integration. Additionally, the integration with a future ERP system must also be taken into consideration.

Consequently, the key requirements for the system were identified, emphasizing the need for integration capabilities with the existing system and future ERP, real-time management of inventory levels, and precise location tracking. The real-time localization aspect assumes critical importance due to the implementation of the chaotic position system utilized in the stock storage of manufacturing unit 3.

Subsequently, an extensive survey of the available WMS options in the market was conducted. Out of the numerous alternatives, a meticulous analysis was conducted on more than 10 options. It swiftly became evident that finding a WMS solution capable of integrating with the existing software was not a straightforward task. Furthermore, the few solutions offering such integration were deemed prohibitively expensive and surpassed the company's budgetary constraints.

To gain further insights, bench marking activities were undertaken by contacting companies sharing similar characteristics. Specifically, companies employing internally developed management software and ERP systems were contacted, revealing that a majority of them had also developed their own WMS solutions.

The primary selection criteria for the WMS revolved around its potential for integration with the existing software and pricing considerations. Following an evaluation of the identified alternatives, it was determined that while three market software options fulfilled the integration criteria, their associated costs were considerably high. Consequently, the ultimate decision was made to undertake internal development of the WMS. The development phase concluded in the middle of March, paving the way for subsequent implementation and user training initiatives, which commenced during the same month.

To facilitate the successful implementation, it was necessary to establish a warehouse location system. This entailed assigning alphabetical designations to the five storage aisles of manufacturing unit 3, along with numeric designations for each position within these aisles. Additionally, the implementation of a barcode and QR code reading system was imperative. With the utilization of these systems, the allocation of gate carts to their respective locations can be achieved efficiently and accurately.

4.4 Integration of Cutting and Inspection Sectors

During the VA/*MUDA* analysis of these two sectors, it was evident that there was a significant amount of material movement solely for the purpose of transferring it from the cutting sector to the inspection sector. Furthermore, the work plan for each sector was determined by the respective team leader, who prioritized tasks based on their subjective assessment of importance. Consequently, this often resulted in the inspection sector failing to adhere to the First-In-First-Out (FIFO) principle.

Through an extensive analysis conducted over a span of two weeks, observations on multiple days, and the examination of the amount of work-in-progress and inspection cycle times, it was discovered that this sector had a buffer that exceeded 1 day of work. More observations also revealed that the second cutter of the machine had the sole responsibility of assisting in picking up the batch of profiles to be cut. Consequently, most of their time was spent on non-value-added activities. Recognizing this inefficiency, the integration of the cutting and inspection sectors was proposed, enabling the inspector to assist the cutter with this task before returning to their primary inspection duties. Furthermore, this integration eliminated the need for material and workers movement between the sectors.

This integration initiative marked the initial step in streamlining the sector, whereby the inspection benches were positioned in front of the profile cutting machines. Consequently, the number of cutters required for the 90º strips, 45º strips, and plumbs cutting machines was reduced, since with the integration, the inspector can help with picking up the batches. However, achieving optimal efficiency necessitated the subsequent balancing of operations to prevent a backlog of WIP on the inspection bench or, conversely, to prevent the inspection process from being halted due to material shortages.

The initial phase of balancing operations involved the collection of cycle times for each operation (cutting and inspection) for the different profiles typologies and dimensions. This was accomplished through a systematic approach of observation, as presented in Figure H.1 in Appendix H, wherein a two-hour time frame was allocated for each profile. During this period, the number of profiles cut and inspected was recorded. With the time necessary per profile to cut and to inspect, it was possible to calculate the number of necessary inspectors per typology, since, as soon as a piece is cut it should start being inspected. Consequently, the number of necessary inspector is then going to be the inspection time per piece divided by the cutting time per piece. The results obtained show that for the different types of profiles, different configurations regarding the number of inspectors are going to be necessary.

Based on the obtained values and the establishment of collaborative tasks, an understanding of the maximum number of inspectors required was achieved. In the case of the 90º strip inspection workbench, a maximum of two individuals is needed when dealing with 100 cm strips. However, for the 45º strips, only one inspector is necessary, as the theoretical values indicate a maximum requirement of 1.2 individuals. In situations where an accumulation of more than 10 strips occurs on the inspection bench, the cutter should assist in opening the profiles and removing the protective plastic. As for the plumb profiles, two inspectors will be required, and the same guidelines regarding the collaboration between the cutter and inspector apply.

4.5 Standard Work

The definition of work instructions and standard work was fundamental for the consolidation of the initiatives implemented and for their good functioning.

At the end of assembly line 1 and 3, the standards shown in Figure I.1 and Figure I.2 in Appendix I was implemented to ensure that after packaging, the kits were allocated to the right cart by the production workers and that no errors occurred when picking them to register them in the WMS.

After establishing this standard for the production operators, it was necessary to also define the standard for the logistics centre workers who collect the carts from the despicking cell to the storage location. This standard breaks down in two work instructions: one for the carts of the three largest clients (referred to as clients A, B, and C), presented in Figure I.3 in Appendix I, and another for the carts of the remaining clients, as seen in Figure I.4 in Appendix I.

The primary distinction between these work instructions lies in the handling of kits from the "Others" cart. Specifically, these kits pass from that cart to the logistics cart in the despicking cell designated for the corresponding client. However, it is important to note that the transfer of these kits to the storage positions in the logistics centre occurs only when the client's logistics cart reaches its maximum capacity, as presented in Figure I.5 in Appendix I. This defined standard is similar for both cells. This approach ensures that the storage process is carried out in a systematic and efficient manner, optimizing the utilization of resources and streamlining the overall workflow.

In the designated cell area, a visual management system was incorporated, featuring a flag mechanism. When there is a shortage of just one kit to complete the filling of a production cart, the flag is activated, with the red side facing the logistics centre. This serves as a clear signal to the logistics operators, indicating the initiation of the put-away process. By employing this visual indicator, the logistics team can efficiently identify and prioritize the carts that require immediate attention. This system enhances communication and coordination between production and logistics operations, ensuring a timely and seamless execution of the despicking process, ultimately contributing to the overall operational efficiency of the facility.

Chapter 5

Results

5.1 Key Performance Indicators Analysis

5.1.1 Productivity

The initial assessment highlighted that the average productivity of operators in the logistics centre, based on historical data from December 2022 to January 2023, stood at 3.51 gates per day per operator. To achieve a targeted 15% increase in productivity, the objective was set to reach 4.04 gates per day per operator.

The final outcomes, depicted in Figure 5.1, were obtained by the conclusion of May 2023. In February, the relocation of manufacturing unit 3 and the consolidation of logistics centres into a unified industrial unit took place. Consequently, productivity temporarily declined due to the transitional phase during which individuals adapted to the new working conditions. However, by March, productivity values were already nearing the targeted level, primarily owing to the implementation of the despicking cell. Furthermore, with the introduction and utilization of the Warehouse Management System in mid-March, a substantial surge in productivity was observed in the subsequent month, April. The elimination of inefficiencies associated with gate searches and the streamlined expedition preparation process resulted in enhanced fluidity. As a consequence, productivity exceeded the project's objectives in April and May, with an average value of 4.66 gates per day per operator. This figure represents a 15% increase over the project's defined goal and an overall improvement of 32% compared to the baseline established.

Assuming a constant demand scenario, this productivity gain signifies the ability to achieve the same number of dispatches with fewer hours worked. For instance, a logistics centre that previously employed 10 individuals, considering 22 working days per month and 7.5 hours of work per day, resulting in 19,800 hours worked per year and 69,498 dispatched gates, can now accomplish the same level of dispatches with 14,914 hours of work, corresponding to a decrease of 24%. Taking into account the minimum wage in Portugal, set at 4.40 euros per hour, this reduction translates into a yearly cost saving of 21,498.4 euros.

The integration of cutting and inspection processes yielded tangible benefits, including a reduction in the number of personnel dedicated to cutting operations by 3 individuals, one for each

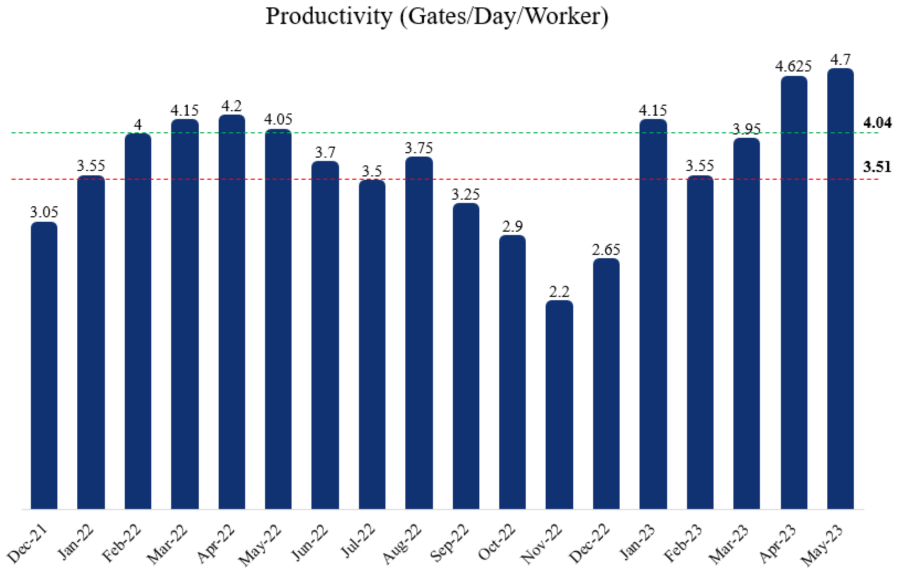

Figure 5.1: Logistics Centre Productivity Values

cutting machine, as well as a decrease of one inspector. The comparison between the number of cutters and inspectors needed before and after integration is presented in Figure J.1 in Appendix J. This optimization of human resources allocation improved operational efficiency within the sector and led to a 30% increase in the productivity of the new sector, and 8% increase in the unit's productivity. Assuming 7.5 hours workdays and 22 workdays per month, this reduction in three workers translates to 5940 less work hours per year (1980 hours per worker), resulting in a yearly cost saving of 26,136 euros.

The integration of the production and logistics centre through the implementation of a despicking cell has resulted in a 20% reduction in lead time. The introduction of this cell has facilitated the seamless flow of goods from production to the logistics centre, enabling multiple gate deliveries throughout the day. In contrast, prior to the integration, gate deliveries occurred only once a day. Consequently, the gates are now readily available for shipment immediately after their production, eliminating the need for additional transit time.

The significance of this integration is evident in the elimination of the last week of lead time that was previously required for shipping the gates. Under the previous system, the gates had to be transported from the production unit to the logistics centre before being dispatched to the end customer. This additional step extended the lead time communicated to customers to a duration of 5 weeks. However, with the integration and the subsequent elimination of this intermediate step, the company has successfully reduced its lead time to 4 weeks.

Figure 5.2 provides an overview of the implemented solutions along with their corresponding KPIs, as well as the achieved outcomes and the resulting financial benefits.

Implemented Solutions	KPIs	Obtained Result	Financial Benefit
Logistics Centre Layout Design	• Logistics Centre Productivity • Lead Time	• +32% Productivity • -1 week in lead time	€ 21,498.4
WMS			
Despicking Cell			
Integration of Cutting and Inspection Sectors	• Manufacturing Unit Productivity	• +8% Productivity	€ 26,136.00

Figure 5.2: Summary of the obtained results

5.1.2 Standard Work

Prior to the implementation of these established standards, it was observed that approximately 10 gates per week encountered errors during the picking process. The primary cause of these errors was attributed to the workers picking the cart first and subsequently picking the gate. As the system failed to detect these errors, the carts were transported to the warehouse with the incorrect gates associated with them.

However, following the implementation of these defined rules and comprehensive operator training, the occurrence of errors stemming from this specific issue was effectively eliminated, reducing the number of such errors to zero. This significant improvement demonstrates the positive impact of the established standards and the proficiency of the trained operators in ensuring accurate gate selection during the collection process.

Nevertheless, at this stage, it remains premature to fully comprehend the actual impact of the implemented initiatives. It is imperative to maintain ongoing monitoring of these identified indicators to assess whether the anticipated outcomes are consistently being realised. By continuously tracking and analysing the established indicators, the project team can gain a deeper understanding of the effectiveness and sustainability of the undertaken measures. This ongoing evaluation will enable them to make informed decisions, refine strategies, and make any necessary adjustments to ensure the desired results are consistently achieved in the long term.

Chapter 6

Conclusion and Future Work Perspectives

In pursuit of enhancing production and logistics operations' efficiency and minimizing lead time, Company X made the strategic decision to integrate these operations by constructing an industrial facility comprising the manufacturing unit and a logistics centre catering to three production units within the organization.

The development of this project aimed to ensure optimal efficiency during the integration process. With a focus on two specific objectives, namely, productivity enhancement and lead time reduction, the project implemented various concepts and tools grounded in the principles of Standard Work and Warehouse Design methodologies. Complementing these methodologies, additional straightforward tools such as the VA/*MUDA* diagram were employed to facilitate the identification of improvement opportunities.

6.1 Main Conclusions

The project has demonstrated successful outcomes in achieving most of the proposed objectives. The primary objective focused on increasing the productivity of the logistics centre. This goal was accomplished through the integration of logistics operations with the production of manufacturing unit 3, specifically through the implementation of the despicking cell. This integration allowed for the segregation of gates by customer and production week, eliminating the need for additional operations upon arrival at the logistics centre. Consequently, the picking process became more efficient, with gates for the same customer mostly consolidated on a single pallet. Furthermore, the implementation of chaotic positions and the Warehouse Management System in the storage locations of manufacturing unit 3 resulted in better space utilization and reduced time spent searching for gates during picking.

The integration of operations also successfully contributed to the objective of reducing lead time by one week. The elimination of the week required to transfer gates from the manufacturing unit to the smaller logistics centres resulted in operations being directly processed and dispatched from the integrated logistics centre. Now, gates are transferred from the manufacturing unit to the logistics centre whenever a production cart in the despicking cell is full, ensuring daily availability of gates for all customers. This streamlined process significantly accelerated gate availability for dispatch.

The layout design of Manufacturing Units 1 and 2 focused on optimizing the existing space, considering the high-demand gate references and the limitations imposed by material dimensions. The main goal was to ensure the best use of the available space while accommodating the movement of materials effectively.

Although the goal of achieving a 15% productivity increase in MU3 was not fully attained, integrating the cutting and inspection processes resulted in a 30% productivity improvement within the sector and an overall 8% improvement for the unit. The implementation of standard work methodologies played a crucial role in reducing errors across processes and consolidating consistent work practices at each workstation. This approach ensured that tasks were consistently performed in the same optimal manner, leading to improved efficiency and quality outcomes.

The accomplishment of the aforementioned results was exclusively made possible through the implementation of a coherent and result-oriented strategy. This strategy is built upon several fundamental pillars, including the utilization of data to characterize the existing situations. This data-driven approach enhances the understanding among stakeholders regarding the current state of affairs and the desired outcomes.

Furthermore, the significance of empowering and integrating individuals throughout the process is underscored. Allowing active participation from team members enables them to contribute to the identification of crucial areas of improvement and the implementation of solutions, some of which may have originated from their own suggestions. This approach fosters a sense of ownership and belonging, which proves to be fundamental in the attainment of the proposed objectives.

6.2 Future Work Perspectives

To achieve the desired productivity in the manufacturing unit, several initiatives can be implemented. One of the key aspects of these initiatives should be the assembly lines, which have been identified as the bottleneck. Understanding the time required for each operation in this sector is crucial, along with associating gates to production time through time collection to determine appropriate team sizes. Customized gates necessitate the creation of clusters based on factors impacting cycle time, enabling the establishment of a reliable database. Calculating the *takt time*, representing the available time to produce one unit in line with customer demand, facilitates the identification of operations suitable for integration and mutual assistance.

Implementing Logistics Internal Flow methodologies, such as *Mizusumashi*, would enhance productivity by addressing component shortages that currently halt operations, preventing operators from having to leave their workstations to access the warehouse. Furthermore, optimizing production planning in the cutting sector can reduce personnel requirements based on the daily production plan, potentially increasing overall productivity.

Improvements to the Warehouse Management System in the logistics centre must also be further developed. Incorporating functionalities that prioritize worker tasks, rather than the current non-prioritized daily work plan, can boost productivity and improve service levels.

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Appendix A

Mass Production and Mass Customization Entity Relationships

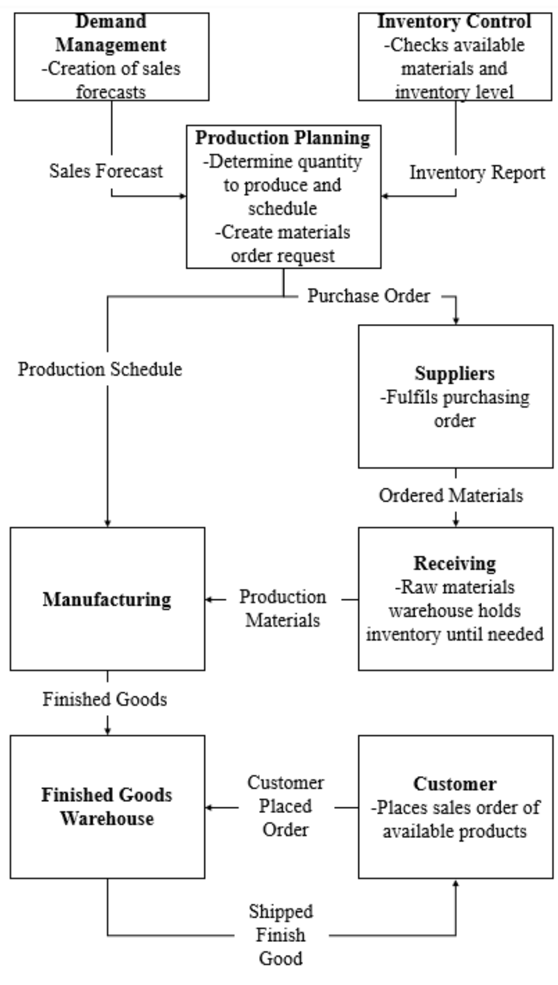

Figure A.1: Entity relationships in mass production. Adapted from Chandra and Grabis (2004).

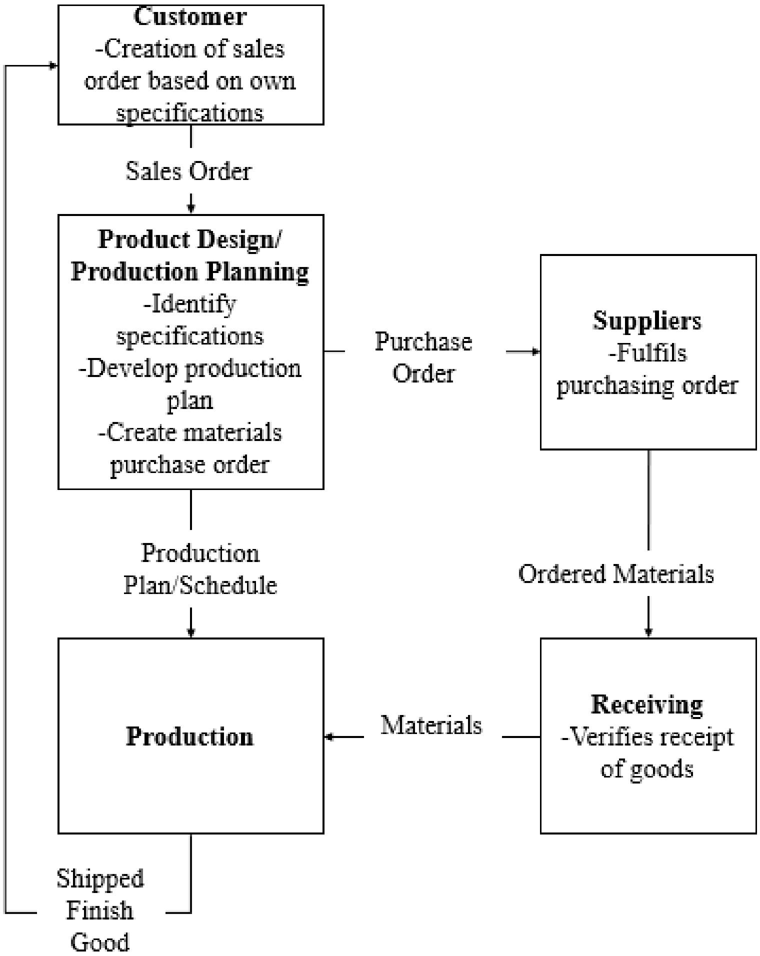

Figure A.2: Entity relationships in mass customization. Adapted from Chandra and Grabis (2004).

Appendix B

Materials Flow Map

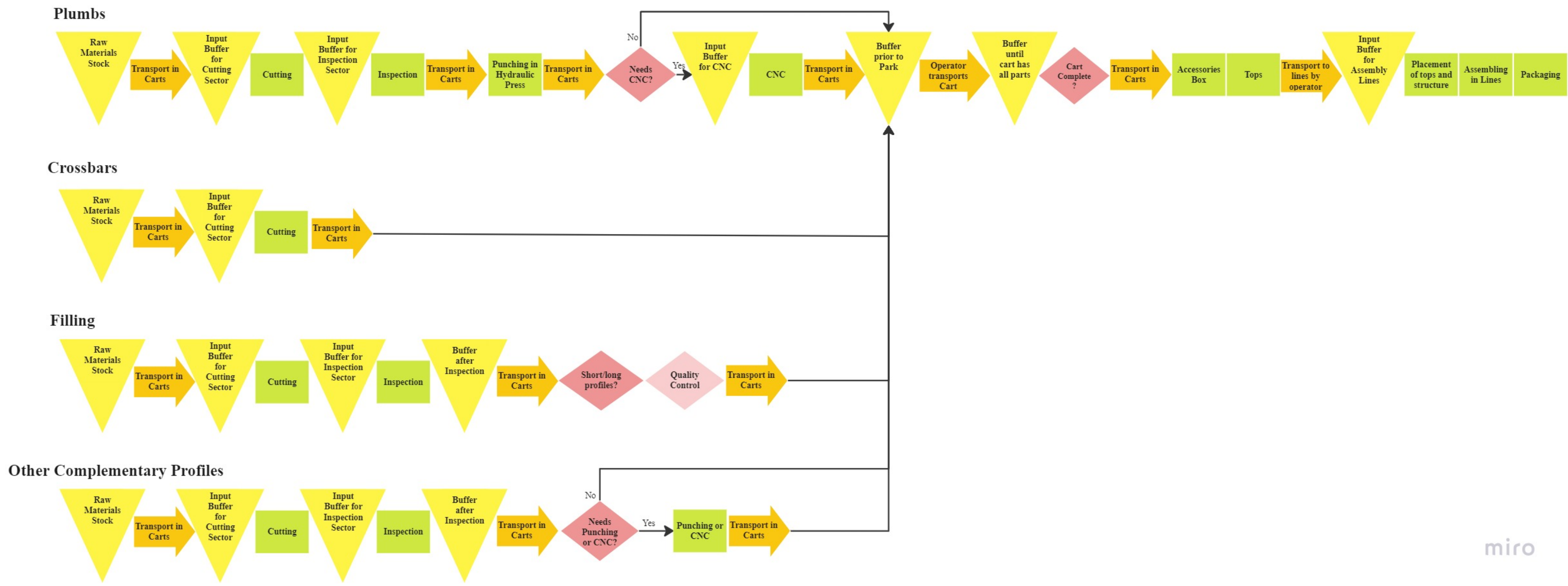

Figure B.1: Characterization of the initial situation - Material Flow

Appendix C

VA/MUDA Analysis and Improvement Opportunities in the Machining Sector

The *muda* activities in the machining sector account for around half (51%) of the total time available for production , as seen in Figure C.1.

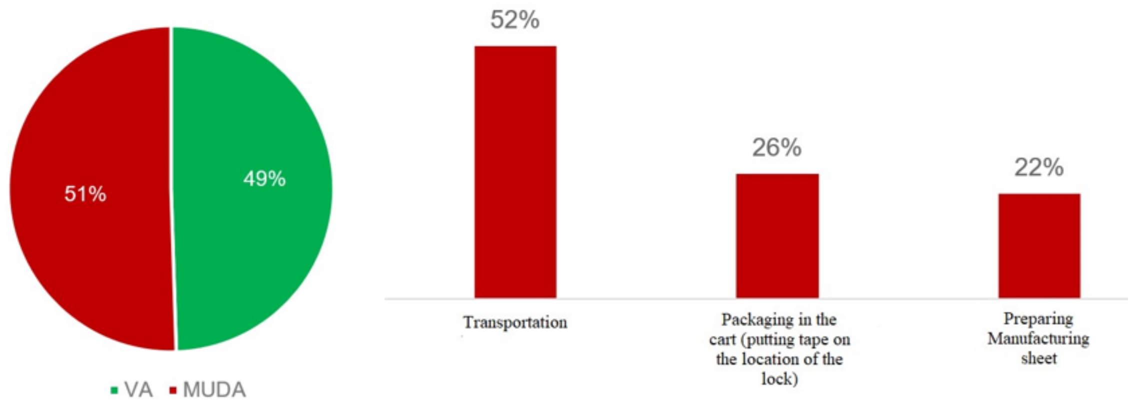

Figure C.1: VA/MUDA Analysis of the Machining Sector

The non-value added time is divided by three operations, which are transportation of material, packaging in the cart (mainly putting tape on the location of the lock), and preparing the manufacturing specification sheet.

The next step was to identify the improvement opportunities in this sector, and the following were discovered:

- A lot of time is spent due to the need to associate the manufacturing specification sheet to each *kit*. This takes around 22% of the time that is identified as non-value added.
- The need to condition the profiles in the cart by putting tape on the lock cut accounts for a significant amount of time in this sector. Understanding if there is another way to perform this task or its' relevance can help increase this sectors' productivity.

Appendix D

VA/MUDA Analysis and Improvement Opportunities in the Logistics Park

The Logistics park exhibits a notable characteristic of allocating a substantial amount of time towards non-value added activities, encompassing approximately 93% of the total time spent. This inefficiency predominantly arises from two distinct operations: overprocessing and cart transportation. Specifically, overprocessing represents 98% of the aforementioned non-value added time, consequently emerging as the most significant unproductive task executed within this domain, as seen in Figure D.1.

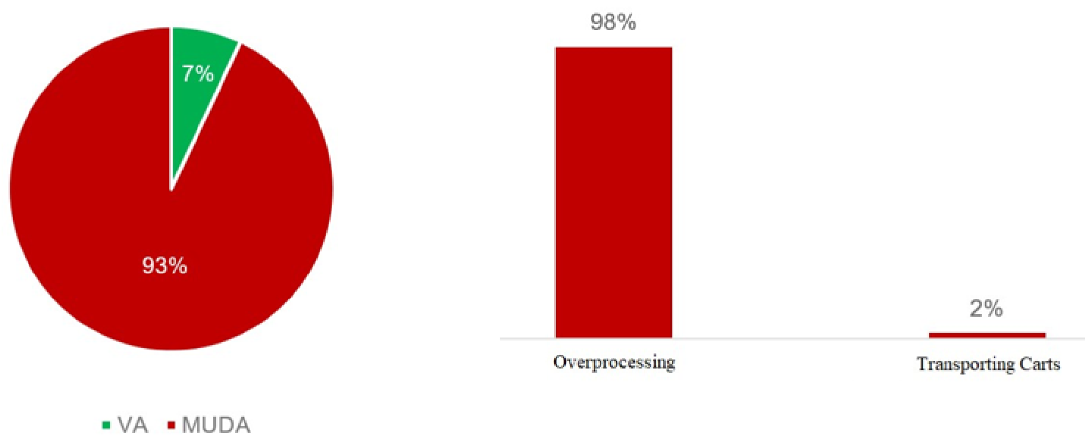

Figure D.1: VA/MUDA Analysis of the Logistics Park

Upon careful analysis of the non-value added activities within the logistics park section, several noteworthy improvement opportunities have emerged. These opportunities have the potential to drive efficiency and productivity gains in the overall operations.

One prominent area of concern is the presence of overprocessing tasks that occur before loading the cart. These tasks consume a considerable amount of time without adding substantial value to the process. By streamlining and reducing the duration of these overprocessing activities, significant improvements in productivity can be achieved.

Another area of focus pertains to the challenges faced by workers in locating the appropriate cart for assembling the required components. This search process incurs unnecessary delays and detracts from overall efficiency. Implementing measures to optimize cart retrieval and allocation can help minimize such delays and streamline operations.

Additionally, the need for workers to validate the readiness of carts before they proceed to the assembly line adds an extra layer of non-value added time. Simplifying and automating this validation process can alleviate this burden and contribute to time savings.

Furthermore, maintaining the principle of First-In, First-Out (FIFO) necessitates the regular repositioning of carts in the queue. This task of relocating and advancing carts consumes valuable time and contributes to inefficiencies. Finding alternative strategies to manage FIFO while reducing the need for frequent cart repositioning can enhance productivity.

Appendix E

VA/MUDA Analysis and Improvement Opportunities in the Assembly Lines

The analysis performed on the assembly lines was divided through the 3 main processes: the assembly of the gate, the cleaning process and the packaging. A VA/MUDA analysis was performed for each, as well as the identification of how much time is spent on non-value added activities, and the improvement opportunities found.

Firstly, on the assembly process it was found that 40% of the total time is wasted in non-value added operations with transportation along the line being the most significant one (49%), as can be seen in Figure E.1. Finding areas for improvement was the next phase, and the following emerged:

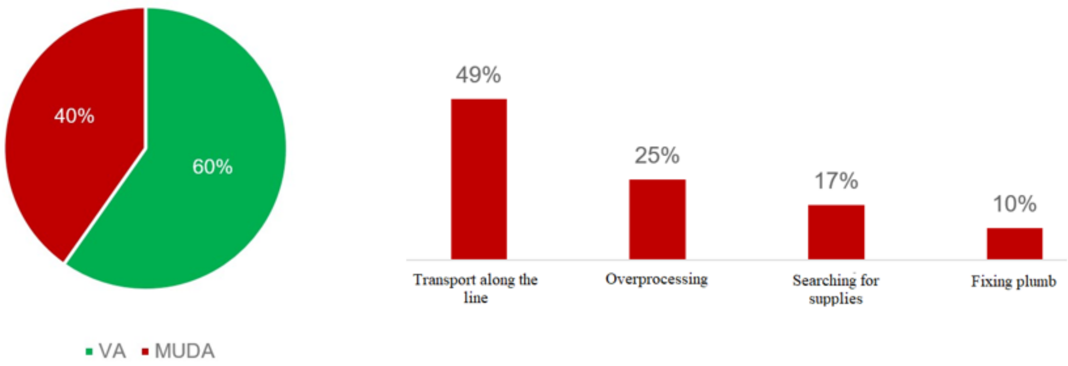

Figure E.1: VA/MUDA and Non-value added operations analysis of the Assembly Process

- A significant amount of WIP is an indicator that operations are unbalanced and that the work is not well distributed between workstations.
- Overprocessing due to errors from the cutting sector. When this happens, the worker in the lines tries to cut the aluminium profile according to its' needs in a support machine that is located in the assembly lines sector. This leads to spending more time than necessary than if all the profiles arrive according to the specifics needs of the sector.
- When a gate moves forward in the line, the worker must push the respective cart with the rest of the profiles to the next workstation. This leads to the worker wasting time in transportation and therefore performing non-value-added activities.

- The time wasted searching for materials can also be significantly reduced by using standardized replenishment techniques and a well-defined border of line.

Next, it was discovered that the cleaning process wastes 27% of its overall time on non-value-added activities, with transportation accounting for the majority of this time (52%), as seen on Figure E.3.

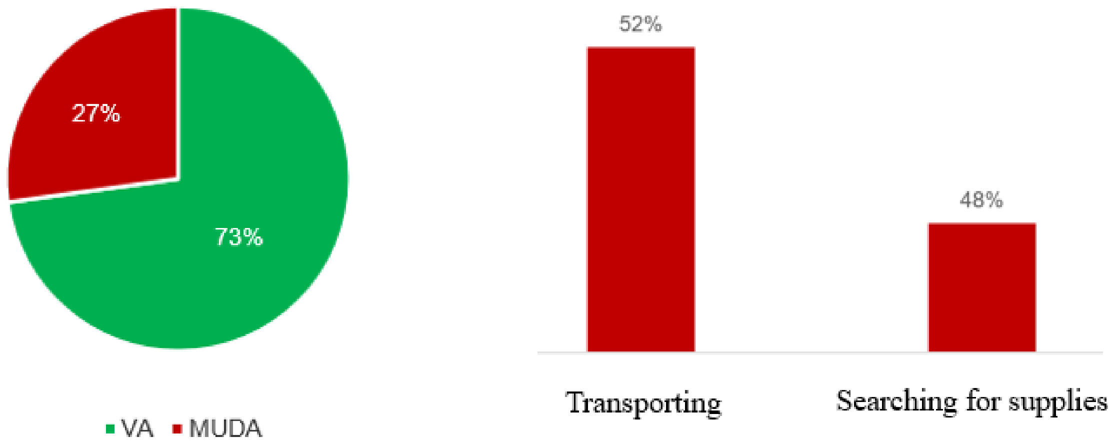

Figure E.2: VA/MUDA and Non-value added operations analysis of the Cleaning Process

The next step was to identify areas that needed improvement, and the following were found:

- Low ergonomics that causes workers to become fatigued during the day.

In the packaging process, the last one in this manufacturing unit, it was found that 49% of the time is wasted in non-value added activities. Of these, all three main non-value added activities represent a significant amount of time since all of them are above 20%. In this process, the following improvement opportunities were found:

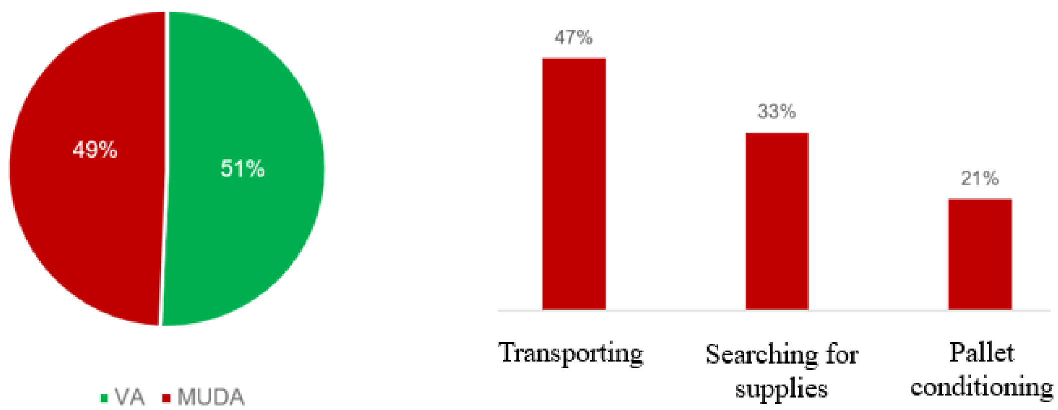

Figure E.3: VA/MUDA and Non-value added operations analysis of the Packaging Process

- High value of WIP right before the start of packaging indicates that this process is the main bottleneck of the unit and that operations are unbalanced.

- There is a high diversity of packaging options due to clients' demands. This leads to a process with high variability in time spent and complicates planning.
- High time wasted in transporting the gate. Firstly, to bring the gate from the previous process to this workstation and after that to put the gate in the pallet.

Appendix F

Complexity Rating per Gate Typology

Typology	Complexity Rating
Opening 1 Sheet	1
Grid Modules	1.05*Opening 1 Sheet
Opening 2 Sheets	2*Opening 1 Sheet
Sliding 1 Sheet	3*Opening 1 Sheet
Sliding 2 Sheet	4*Opening 1 Sheet

Figure F.1: Complexity Rating per Gate Typology

Appendix G

Logistics Centre SKU's allocation to Stock Corridors

	Stock Corridor A (<2.1m)	Stock Corridor B (<2.1m)	Stock Corridor A (>2.1m)	Stock Corridor B (>2.1m)	C Zone	Reinforcement Zone
Length of stock position	25.3	13	25	14.45	17	15
Nr of stock positions	56	44	37	33	18	30
A References (<2.1m)	56	6	0	8	0	0
B References (<2.1m)	0	29	0	0	0	0
A References (>2.1m)	0	0	37	0	0	0
B References (>2.1m)	0	0	0	25	0	0
C References	0	9		0	36	18
Fulfilled Positions	56.0	44.0	37.0	33.0	18.0	18

Figure G.1: Summary of SKU's Allocation to Stock Positions

Appendix H

Collected Data for the necessary number of inspectors calculation

Profile Typology	Cutting Time (seconds/piece)	Number of pieces cut/hour (1 person)	Inspection Time (seconds/piece)	Number of pieces inspected/hour (1 person)	Necessary inspectors
Strips 100 - 90º	15	238	31	118	2.0
Strips 200 - 90º	36	100	36	100	1.0
Strips 280 - 90º	36	100	61	59	1.7
Strips 116 - 45º	90	40	108	33	1.2
Strips 200 - 45º	95	38	108	33	1.1
Plumbs	45	80	99	36	2.2

Figure H.1: Data collected from observations in cutting and inspection sector

Appendix I

Job Instructions for Standard Work

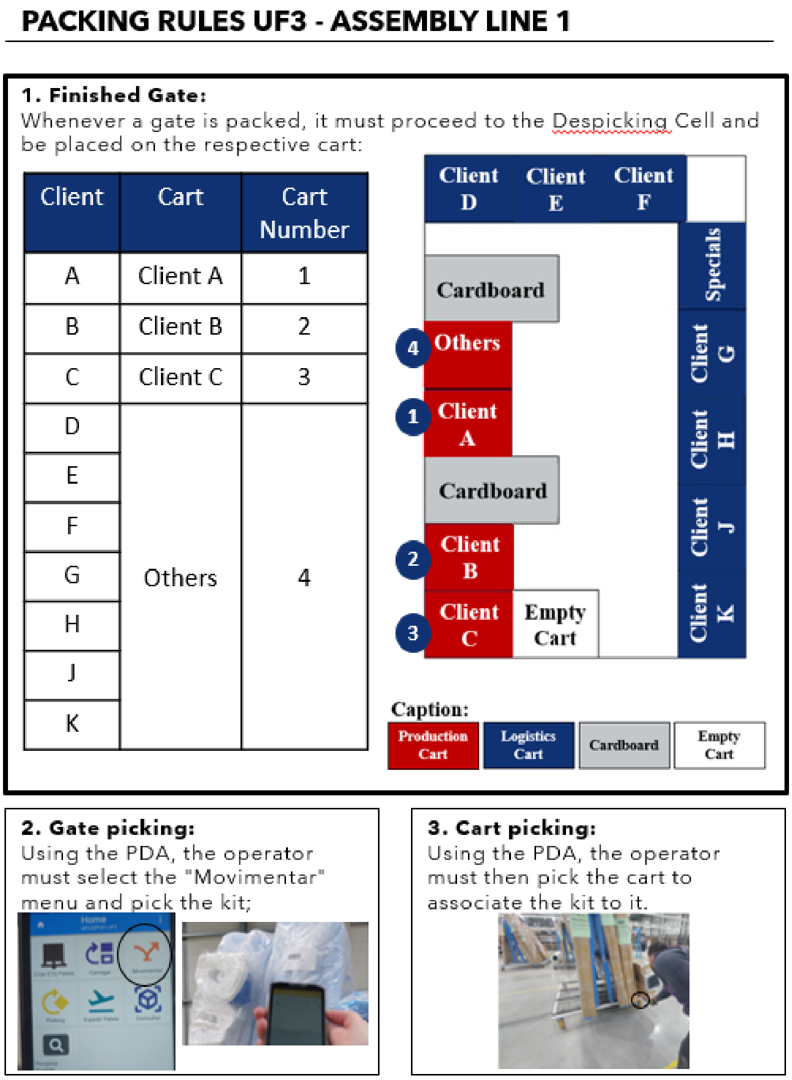

Figure I.1: Packaging Rules - Assembly Line 1

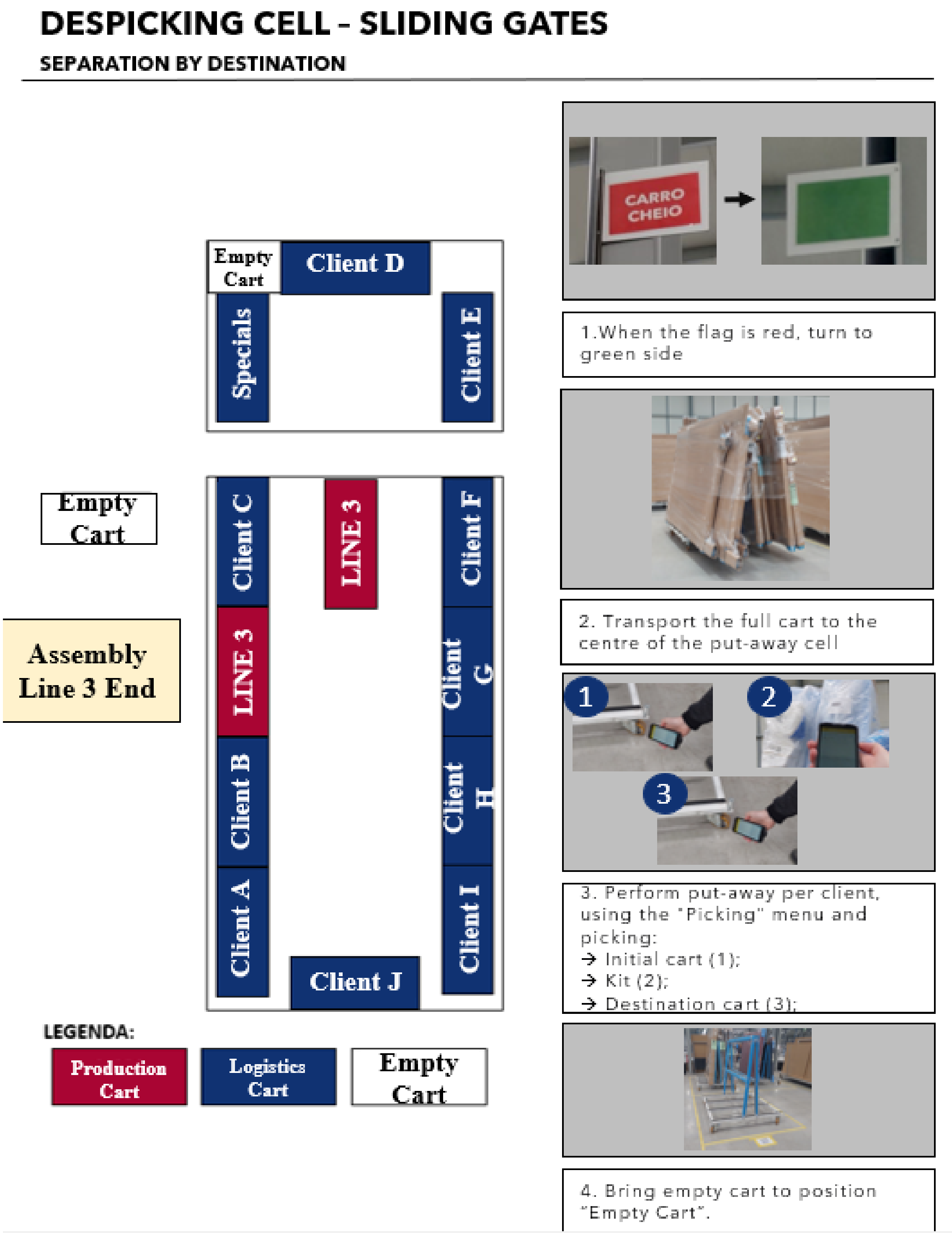

Figure I.2: Separation By Destination in Despicking Cell - Assembly Line 3

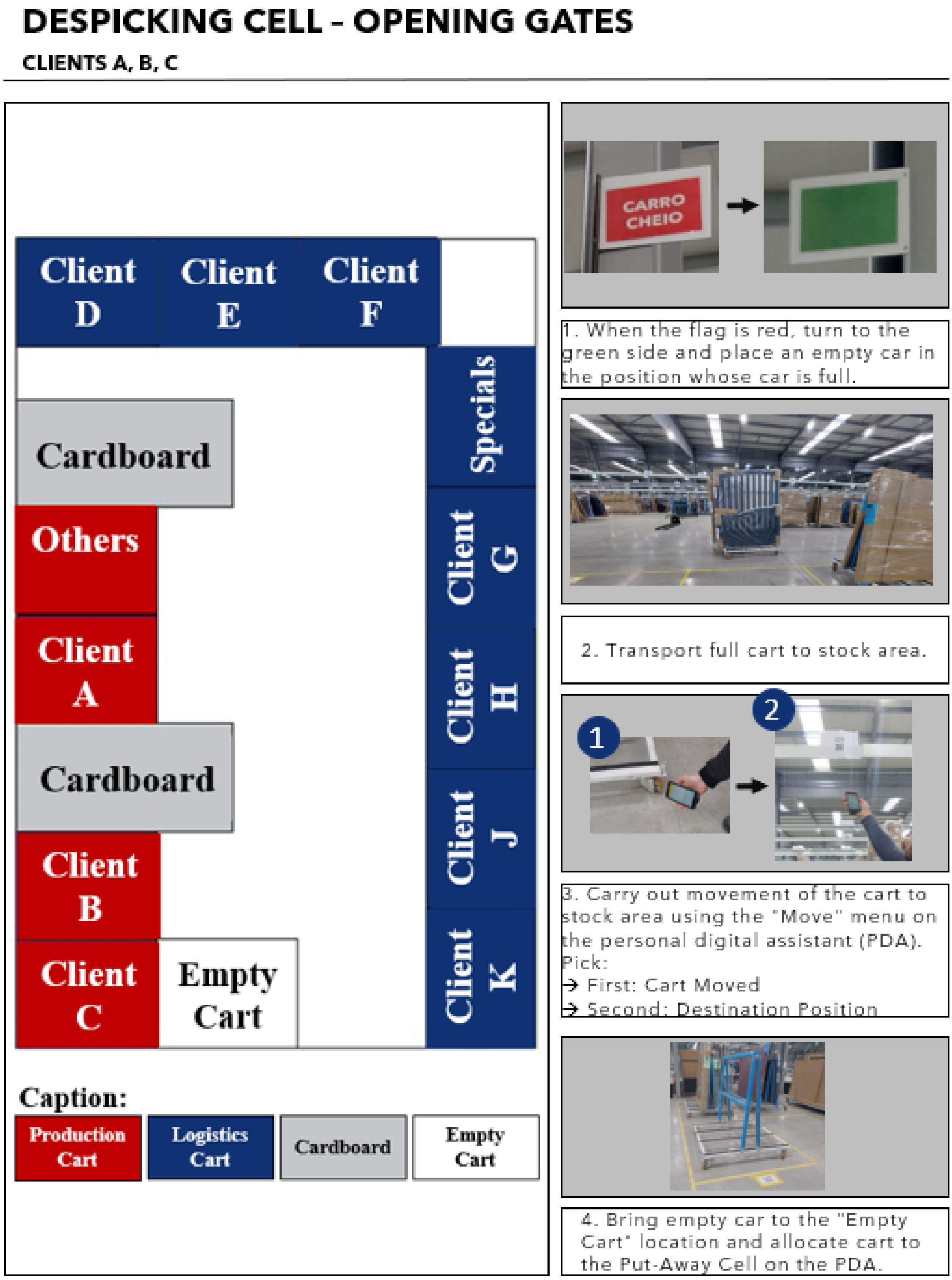

Figure I.3: Despicking Cell for Opening Gates to Clients A, B and C - Job Instructions

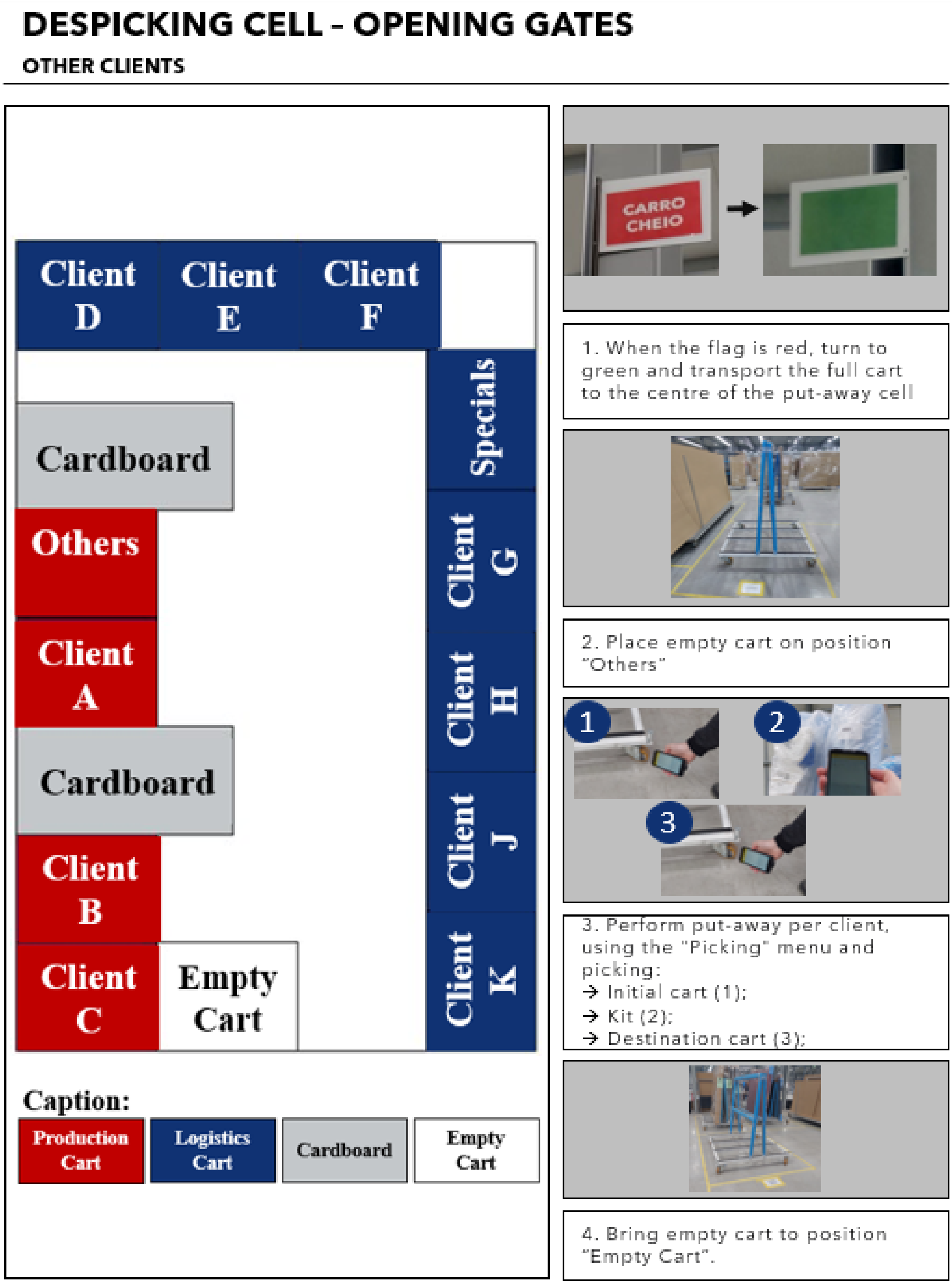

Figure I.4: Despicking Cell for Opening Gates to Other Clients - Job Instructions

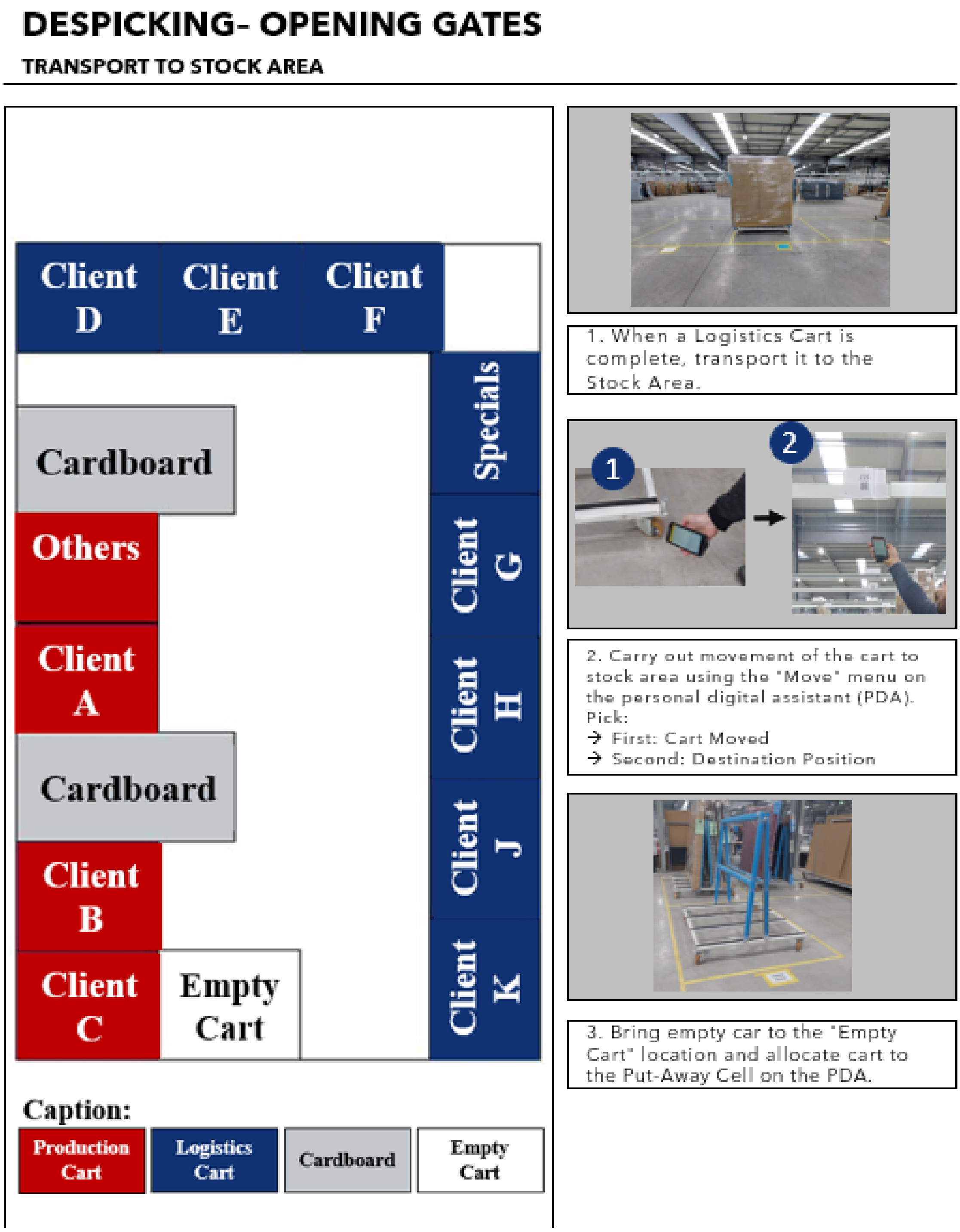

Figure I.5: Carts Transport to Stock Area - Job Instructions

Appendix J

Comparison of the number of required personnel before and after integration of cutting and inspection

	Before integration		After integration	
Profile Typology	**Cutters**	**Inspectors**	**Cutters**	**Inspectors**
Strips 90°	2	4	1	2
Strips 45°	2		1	1
Plumbs	2	2	1	2
Total	6	6	3	5

Figure J.1: Necessary workers before and after integration