

Boosting Automated Warehouse Productivity: Gamifying Order Picking and Digitalizing KPIs

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Master's Dissertation

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Mestrado em Engenharia e Gestão Industrial

2023-07-14

Abstract

Nowadays, the standards and competition of supply chain operations are higher than ever. Supply chain, logistics and operations have to be carefully managed and measured to guarantee smooth and efficient functioning and deliver the right product at the right standards at the right time. And this all starts in the picking operation, where commonly, cost and turnover rates of warehouse operations are highest due to its repetitive nature, demands and environment, and where engagement of the workers is lowest. The use of gamification on everyday apps and work environments has been shown to increase the motivation and engagement of workers, thus enhancing overall business performance.

This project was based at a paint and coatings company, *Corporação Industrial do Norte, S.A. (Tintas CIN)* and consisted of the co-development of a gamification app and features with a start-up company, *Vaibe*, to the picking area of the automated warehouse of CIN's Distribution Center, to increase productivity and engagement of the workers and change the way productivity metrics are viewed and calculated.

A literature review is given around supply chain management, logistics and warehouse concepts present in this operation, KPIs definition and visualization of metrics in a dashboard, and gamification, all to correctly support the proposals of this project. Afterwards, a complete categorization of the current state was achieved by closely monitoring the daily work in the picking section and its many details. A record of machine breakdowns that affect the throughput of pallets and successive calculations of non-existent maintenance indicators through this sample was done. In addition, a detailed breakdown of key factors of the operation that are impacting productivity as well as a statistical data analysis of picks was performed. All of this led to key findings for an adequate suggestion on how to adapt gamification to this sector and the suggestion of KPIs for a more effective performance measure. From this, the focus of the project consisted of four main implementations: Digitalisation and visualisation of KPIs in a dashboard; Application for recording machine errors; Public display in the picking area of past and real-time updated metrics of this sector; Definition of competition-based game plans to promote motivation and engagement.

Because this project is ongoing and follows an iterative process, and the short timeframe of the dissertation period, this period corresponded to the detailed definition and planning phase of the improvement suggestions, and they could not be implemented in time. However, with careful development of each major implementation, it is believed that this pilot project should give CIN a competitive advantage over other players in an increasingly competitive market and change the way order picking work is viewed, both in the way performance is measured and in employee engagement.

Resumo

Atualmente, os padrões e a concorrência das operações logísticas são mais elevados do que nunca. A cadeia de abastecimento, a logística e as operações têm de ser cuidadosamente geridas e avaliadas para garantir um funcionamento suave e eficiente e fornecer o produto certo, com os padrões certos e no momento certo. E tudo isto começa na operação de separação de encomendas, onde normalmente as taxas de custo e de rotação de trabalhadores são mais elevadas devido à sua natureza repetitiva, exigências e ambiente, e onde o envolvimento dos trabalhadores é mais baixo. A utilização da gamificação em aplicações quotidianas e ambientes de trabalho tem demonstrado aumentar a motivação e o envolvimento dos trabalhadores, melhorando assim o desempenho geral da empresa.

Este projeto teve como base uma empresa de tintas e revestimentos, a Corporação Industrial do Norte, S.A. (Tintas CIN) e consistiu no co-desenvolvimento de uma aplicação de gamificação e funcionalidades com uma empresa start-up, a Vaibe, para a área de separação do armazém automático do Centro de Distribuição da CIN, para aumentar a produtividade e o envolvimento dos trabalhadores e mudar a forma como as métricas de produtividade são vistas e calculadas.

Foi feita uma revisão da literatura em torno da gestão da cadeia de abastecimento, dos conceitos de logística e de armazém presentes nesta operação, da definição de indicadores de performance e da visualização de métricas num dashboard, e da gamificação, para suportar corretamente as propostas deste projeto. Posteriormente, foi realizada uma categorização completa do estado atual através do acompanhamento do trabalho diário na secção de picking e dos seus vários detalhes. Foi efectuado um registo das avarias de máquinas que afectam a produção de paletes e cálculos sucessivos de indicadores de manutenção inexistentes através desta amostra. Além disso, uma análise detalhada dos principais factores da operação que estão a afetar a produtividade foi realizada, bem como uma análise de dados estatísticos das separações de encomendas. Tudo isto levou a conclusões chave para uma sugestão adequada sobre como adaptar a gamificação a este sector e a sugestão de KPIs para uma medida de desempenho mais eficaz. A partir daí, o foco do projeto consistiu em quatro implementações principais: Digitalização e visualização dos KPIs num dashboard; Aplicação para registo de erros das máquinas; Monitor disponível na área de picking de indicadores passadas e actualizadas em tempo real deste sector; Definição de planos de jogo baseados na competição para promover a motivação e o empenhamento.

Devido ao facto deste projeto estar em curso e seguir um processo iterativo, e do curto espaço de tempo do período da dissertação, este período correspondeu à fase de definição detalhada e planeamento das sugestões de melhoria, que não puderam ser implementadas a tempo. No entanto, com o desenvolvimento cuidadoso de cada uma das principais implementações, acredita-se que este projeto-piloto deverá conferir à CIN uma vantagem competitiva face a outros intervenientes num mercado cada vez mais competitivo e alterar a forma como o trabalho de preparação de encomendas é encarado, quer na forma como o desempenho é medido, como também no envolvimento dos colaboradores.

Acknowledgments

It is a strange feeling to finally reach this chapter of my academic life. These years have been filled with doubts and hardships along the way, with even a global pandemic in the middle, but at the same time, they were the most important time period in my life and growth experience I could have ever hoped for. It has been a true privilege to have crossed paths with many people along the way, for which I would like to show my gratitude and consideration.

First, I thank *Corporação Industrial do Norte, S.A. (CIN)* for the opportunity to apply the knowledge I acquired throughout these years at the start of my professional experience.

To the Logistics team, thank you for the welcome and the good cooperative environment. To Diogo Neto, the company's supervisor, I'm grateful for the guidance and learning opportunities you provided throughout this project, as well as the trust to carry it out. To Dr. Cátia Leite, thank you for the example and support during this time. To Emanuel Antas, I'm thankful for your friendship and confidence that started during our time at FEUP and still continues.

Finally, to the employees of all sectors of the Distribution Center, and especially Picking, your cooperation and knowledge led the way to the understanding of this operation and the foundation for this project's success.

Regarding Vaibe, these months were a great fun collaborative experience, and I would like to thank you for the help and availability to provide me with what I needed regarding the knowledge of your app and the correct application of gamification concepts.

On the academic side, I would first like to show my gratitude to Dr. Maria João Pires, my supervisor at FEUP, for her knowledge, incredible support and consideration shown throughout this dissertation period. For providing the academic background necessary, thanks to FEUP and *INSA Lyon*. I feel proud to be an Engineering student and soon to be Engineer.

On a personal side, to the "family" I obtained in FEUP, without whom I would not have succeeded, I will carry all the experiences, memories and learnings I had with you for a lifetime. To *Grupo de Fados de Engenharia (GFFEUP)*, It's one of my biggest privileges to be able to sing and share the stage with you and here's to many more years of memories and (Monumental) Serenades.

To my family and friends who are on an island in the Atlantic Ocean: It hasn't gotten much easier to leave, but it's comforting to know that I will always be back as if time hadn't passed at all. Thank you for always believing in me throughout this journey and forever. To my mother, Lúcia, thank you for all your patience and support, you deserve the world. Finally, to my father, Fernando, I wish you were still here with us to share this moment and many more with you. I hope to have made you proud.

"One day, in retrospect, the years of struggle will strike you as the most beautiful."

Sigmund Freud

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Acronyms and Symbols

ANOVA - Analysis of Variance
AW - Automated Warehouse
AS/RS - Automated Storage and Retrieval Systems
CIN - Corporação Industrial do Norte, S.A.
CS - Compact System
DC - Distribution Center
DPD - Digital Picking Display
e.g. - exempli gratia
ERP - Enterprise Resource Planning
FEFO - First Expired First Out
FTA - Fault Tree Analysis
i.e. - id est
ML - Miniload
MTBF - Mean Time Between Failures
MTTF - Mean Time To Failure
MTTR - Mean Time To Repair
OEE - Overall Equipment Effectiveness
KPI - Key Performance Indicator
SCM - Supply Chain Management
T1 or TD - Day Shift
T2 or TN - Night Shift
TE1-TE5 - Stacker Cranes of the Automated Warehouse (1-5)
TPM - Total Productive Maintenance
ULMA - Ulma Handling Systems
WMS - Warehouse Management System

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Chapter 1

Introduction

The development of the project was carried out in the Distribution Center of Tintas CIN - Corporação Industrial do Norte, S.A., as part of the Master in Industrial Engineering and Management in the Faculty of Engineering of the University of Porto.

1.1 CIN - Corporação Industrial do Norte, S.A.

1.1.1 Company Presentation

Tintas CIN is a Portuguese paints and coatings firm that was founded in 1917 and is based in Maia, where its main liquid paints factory is located, as well as a Research and Development (R&D) centre and a Distribution Center (DC). The company has more than 100 years of experience and has been the Portuguese market leader since 1992 and the Iberian market leader since 1995. In Europe, it is the 10th largest paint company, according to the European Coatings Journal (May 2023) and the 35th in the world, according to the Coatings World Top Companies Report (August 2022), with a turnover of 389 million euros in 2022 (CIN, 2023).

CIN produces paint coatings for construction, industry, corrosion protection and yachting and marine segments, shown in Figure 1.1.

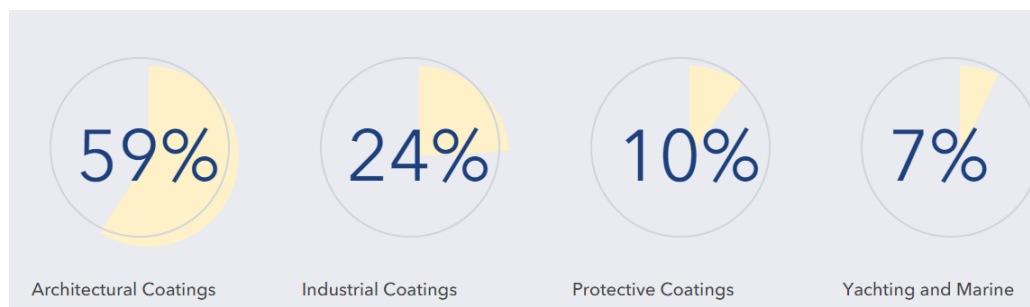


Figure 1.1: Sales Percentage per Business Unit. Adapted from Oliveira (2023)

Tintas CIN is also present in more than fifteen countries and sells in more than 50 countries (shown in Figure 1.2.)



Figure 1.2: International locations of CIN Group's Production, R&D and Sales. Adapted from Oliveira (2023)

The strategic priority of the company led to a major investment in an automated warehouse, that centralized all the group's distribution in Portugal into a single centre, which allowed for an increase in the efficiency of the logistics function and productivity and a significant reduction in operating costs.

1.1.2 CIN Maia's Distribution Center

CIN's distribution center (Figure 1.3) in Maia opened in 2004. The DC functions as a storage and distribution unit, loading vehicles for domestic and international distribution daily and unloading and storing finished products from internal and external suppliers. These processes of reception and distribution lead to a fast and effective response to clients' frequent demands.



Figure 1.3: Outside view of the Distribution Center. Adapted from Oliveira (2023)

The automated warehouse (Figure 1.4) is the heart of the distribution center's operation. It was supplied by ULMA Handling Systems, a logistics automation company based in Spain, and consists of two storage areas and systems:

- Pallet Warehouse (Compact System): There are five central aisles, and each has an automated stacker crane capable of picking up and storing pallets on two racks on both sides.
- Miniload Warehouse (Fine Stocker): Has one central corridor with two racks on each side where a stacker crane moves.

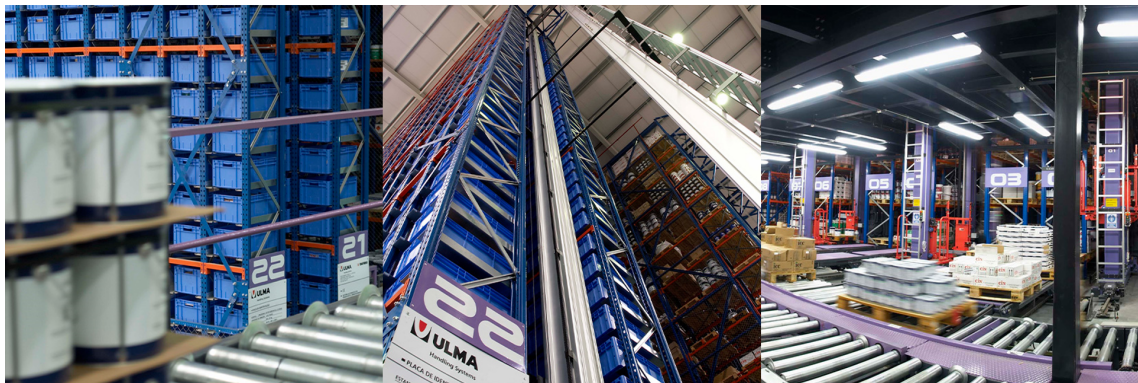


Figure 1.4: View of the Automated Warehouse (ULMA, 2023)

1.2 Project Background, Motivation and Goals

The present dissertation is inserted in the Distribution Center's Logistics Department (Figure 1.5) which is subdivided into different sectors.

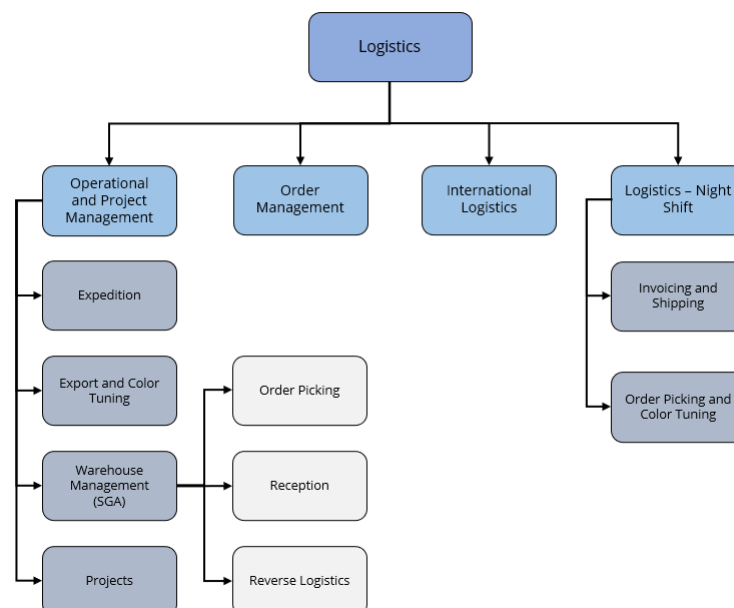


Figure 1.5: Organogram of CIN's Logistics department, adapted from internal file

This project aims to apply the concept of gamification, an increasingly trending theme in the last few years, in the order-picking operation of the automated warehouse to increase the productivity and efficiency of this operation and engagement among employees. The use of gamification on everyday apps and work environments has been shown to increase the motivation and engagement of workers of various sectors, thus enhancing overall business performance.

Nowadays, the standards and competition of supply chain operations are higher than ever. Supply chain, logistics and operations have to be carefully managed and measured to guarantee smooth and efficient functioning and deliver the right product at the right standards at the right time. And this all starts in the picking operation, where commonly, cost and turnover rates of warehouse operations are highest due to its repetitive nature, demands and environment, and where engagement of the workers is lowest.

Gallup's State of the Workplace 2023 (Gallup, 2023) features annual findings from the world's largest ongoing study of the employee experience. According to the report, engaged employees thrive in the work and feel connected to their team and organization. In the last year, only 23% of the world's employees were considered engaged, 59% were deemed as low disengaged and the remaining 18% actively disengaged. Gallup estimates that low engagement costs the global economy US\$8.8 trillion and accounts for 9% of global GDP. Additionally, low engagement can lead to higher rates of absenteeism and turnover, as well as lower levels of productivity and customer satisfaction. By contrast, organizations that invest in employee engagement can see significant benefits: higher productivity levels, profitability, and customer satisfaction. Other studies find that higher engagement generally leads to better company performance and this can be a source of competitive advantage (Bakker et al., 2008; Harter et al., 2020).

CIN's order-picking operation is deemed demanding due to efforts and elevated standards given the service level and quality standards of the company. In addition, problems related to the maintenance of the equipments of the automated warehouse are frequent and time costly for the picking workers that fix these issues. This sector has experienced the highest turnover rate when compared to other sectors of CIN, in the last few years. According to the US Bureau of Labor Statistics, employee turnover in the warehouse industry stands at 44% (of Labor Statistics, 2023). The main factors for this are given by Min (2007): Lack of job security and tense working environment. Contrary to popular belief, a lack of financial incentives was not the main factor.

1.3 Methodology

The assignment at hand consisted of the development process of a pilot project of implementing a Gamification app provided by an external start-up company to CIN's order-picking operation in the automated warehouse. The initial goals of the project were to digitalize KPIs and implement competition-based games to increase the motivation and engagement of the workers in the picking area and measure the impact of this on productivity.

To correctly apply this concept, gamification has to be adequate to the operation and the workers, so firstly, extensive close monitoring of the operation and understanding of concepts was

necessary, which allowed to identify issues and areas of improvement regarding maintenance and performance measurement, from a detailed study of machine breakdowns, the KPIs utilised and picks data. After this process, the following main implementations were decided to be developed: The priority was the digitalisation and visualisation of metrics through a public display in the picking area and a dashboard for managers; An app on tablets for logging machine breakdowns and finally definition of future game plans to increase motivation and engagement of the workers. With the short timeframe of the dissertation and the fact that this is an ongoing project, results couldn't be obtained on time. Still, detailed considerations, next steps and expected results were planned and considered.

1.4 Dissertation's Structure

The dissertation is divided into five chapters, one of which corresponds to this introductory chapter. The following, Chapter 2, presents the results of research about the key topics and theoretical concepts related to the project to serve as a basis for considerate planning of the different implementation ideas. These topics include subjects such as warehouse logistics, automation of processes in this sector, key performance indicators and maintenance, and an overview of gamification.

Chapter 3 gives a complete detailed analysis of the automated warehouse operation, with a breakdown of the picking function and how performance is measured in this sector. A detailed study of machine breakdowns that are impacting the operation and non-existent maintenance indicators are estimated, and further results of a statistical analysis of picks data for further insights are provided, culminating in the challenges to solve in terms of maintenance and how the productivity of the operation is calculated and visualized.

Chapter 4 describes the suggestions for new performance measures and the methodology of the different implementation proposals during the project, with a detailed overview of the planning process of each, the next steps and expected results, since no solution could be implemented completely on time.

To finalize, Chapter 5 mentions the conclusions, limitations and considerations for future work and continued success of the project.

Chapter 2

Literature Review

For any successful project development and implementation, it's essential to perform extensive research to understand the state of the art of the main topics covered. Therefore, this chapter presents the key concepts interconnected to the project. Firstly, a review of the relevant Supply Chain and Logistics topics is given, specifically automated processes in warehouses. Afterwards, an overview of KPIs (Key Performance Indicators) is presented: definition, goals, common metrics of this sector, as well as the importance of good dashboard design. Later, maintenance topics are covered and an overview of Gamification, the concept and applications, is given.

2.1 Supply Chain and Logistics Management

A Supply Chain is made up of all the intervenients involved in meeting consumer demands, from Suppliers and Manufacturers, Distributors, Warehouses, and Retailers, all the way to the final Client, with the aim of maximizing the generated value at minimum costs across all stages (Chopra and Meindl (2013)). It is therefore, essential that a Supply Chain is adequately managed.

SCM (Supply Chain Management) is the planning and management of all sourcing, procurement, conversion, and logistics operations. It includes supply and demand management across organizations and channel partner coordination (CSCMP, 2013). A similar definition is given by Lummus et al. (2001): Supply chain management includes all logistical flows, customer order management, production processes and information details required to monitor all supply chain operations. Within the topic of Operations Management, the ideas of SCM and Logistics Management are connected but differ.

Christopher (2005) characterises Logistics as the process of strategically controlling the acquisition, movement, and storage of raw materials, finished goods, and connected information streams through the organization and marketing channels to maximize current and future profitability through the efficient fulfilment of orders. CSCMP (2013) describes that Logistics Management is known as the subset of SCM concerned with the planning, implementing, and control of the efficient, effective forward and reverse flow and storage of goods, services, and related details

between the point of origin to the point of consumption, with the goal of fulfilling customer demands. Typical logistics management tasks consist of: Inbound and outbound transportation management; fleet management; warehousing; materials handling; order fulfilment; network design, inventory management, supply/demand planning; and management of third-party logistics service providers. It also includes sourcing and procurement, manufacturing planning and scheduling, packaging and assembly, and customer support.

Furthermore, Logistics follow seven principles (7R), that are defined by Michlowicz (2013) as "the delivery of the right product (R1), in the right quantity (R2), of the right quality (R3), to the right place (R4), at the right time (R5), at the right price (R6), to the right customer (R7)".

In summary, SCM has a broader scope and encompasses strategic coordination and optimization of all supply chain activities. Logistics specifically deals with the physical movement and storage of goods within the supply chain. Effectively connecting both can lead to significant competitive advantage (Christopher, 2005).

CIN's Distribution Center follows a logistical flow with the activities depicted in the literature.

2.2 Distribution Center Logistics

This is an extensive subject and a crucial component of a Supply Chain and Operation for the success of businesses. It regards the material flow within a warehouse and its goal is to minimize cost and maximize efficiency of processes and level of service. To provide a general idea, CSCMP (2013) defines the concept of a warehouse as a goods storage facility and a Distribution Center as a warehouse facility where inventory from suppliers is stored until it is distributed to the intended clients.

2.2.1 Main Processes

Gu et al. (2007) describe the basic requirements and processes of these facilities as receiving SKUs (Stock Keeping Units) from suppliers, storing them, retrieving SKUs when orders from customers are received and then assembling the complete orders for shipment and distribution. These procedures can thus be labelled as Reception, Storage, Order Picking and Shipping and detailed by Berg and Zijm (1999): Reception concerns the unloading of goods transported by trucks at receiving docks, where quantities and quality of products are confirmed. Following that, the cargo goes to an assigned position within the warehouse (Storage). When a product is needed, a customer's order specifies the items and quantities desired, it has to be taken from storage (Order Picking) and when there are many product references in an order, they have to be sorted and aggregated before being sent to the shipping area, where they are sent to the client.

Storage management and order picking have the biggest influence on the overall performance of a warehouse due to the importance of the efficiency of order picking and storage capacity and utilization of space (Gu et al., 2007). The picking operation is usually considered in the literature as the most costly and labour-intensive process in a warehouse. de Koster et al. (2007) mention that this process accounts for a significant portion of overall operating expenses (estimated at 55%)

since shortcomings in this process lead to poor service and increased operational costs (de Koster et al., 2007). To understand the source of errors in the picking process, a study by Setayesh et al. (2022) identified a few factors that impact workers' performance: the amount of workload, physical and mental exhaustion, memory demands, eyesight, hearing and motivation. Facilitating the effort and flow of the picking process to minimize errors is the key to the operation's success since rapid and effective picking with no mistakes leads to higher customer satisfaction and, therefore, business performance.

2.2.2 AS/RSs and Warehouse Management Systems

Innovative technological approaches being used to facilitate these processes and improve efficiency involve using automation in storage and picking processes and the digitalisation and tracking of inventory through WMS (Warehouse Management Systems). Regarding automation levels in a warehouse, Berg and Zijm (1999) depicts three types of warehousing: Manual picker-to-product systems, automated product-to-picker systems, and automatic warehousing systems.

A survey of literature on AS/RS (Automated Storage and Retrieval Systems) by Roodbergen and Vis (2009) describes them as computer-controlled automatic storage and transport facilities commonly used in high-volume distribution centers for handling pallets of goods. The key features are storage racks placed along aisles where stacker cranes are bounded to and move along them, to retrieve or store pallets in these racks. Items moved for picking or to be stored are placed into input/output points at the entrance of the aisles. The products are moved without human intervention, so this procedure is totally automated. Although the costs of implementing this kind of system are high, the benefits outweigh them due to boosts in reliability, speed and efficiency. In addition, inventory management policies such as class-based ABC allocates items to the available space based on their rotation frequency. This means these products are stored near the entrance point of the aisles, and this way, efficiency is increased. de Koster et al. (2007) say that at the pick position, the worker takes the required number of pieces, after which the pallet is stored again, and an AS/RS containing bins instead of pallets is referred to as Miniload.

Warehouse Management Systems are also integrated within this type of system. Since being implemented in the 1970s, they have been trending due to warehouse automation and supply chain software (Min, 2006). Before this type of system, records were based on paper and operations were done manually, which led to errors, took a lot of time and ended up being costly (Andiyappillai, 2020). WMS functions by regulating material flow and storage inside a warehouse and handling all previously mentioned operations (receiving, storing and picking). Data of warehouse movements is continuously tracked to maintain accurate inventory management and improve operations (Ramaa et al., 2012). Additionally, they optimize the pick and storage assignment sequences in the warehouse automatically, which reduces labor efforts and increases order accuracy. Warehouse Management Systems are normally integrated with the company's Enterprise Resource Planning software (Min, 2006).

2.2.3 Automated Order Picking

Regarding order picking, automation has also helped to reduce pick errors. Pick-to-light systems use clear instructions and visual aids. Battini et al. (2015) explains that lights that turn on the respective picking locations displaying the number of items to remove help to guide the operators, and to fulfil the pick, the workers have to press the respective button in the location or in some systems scan the barcode of the item. The benefits of these systems are the clearness of changes in inventory, the ability to process orders in parallel and the reduced reaction time which results in an increased picking performance. These systems are normally incorporated within Warehouse Management Systems (Min, 2006).

Present in CIN's Automated Warehouse are Automated Storage and Retrieval Systems, WMS integrated with ERP (Enterprise Resource Planning) and the use of pick-to-light in the picking posts. This leads to very efficient inventory management, a high flow of products through the warehouse and a reduction in picking errors.

2.3 Key Performance Indicators

2.3.1 Goals and Classification

Metrics associate the state of operations with objectives. As defined by George (1981), KPIs (Key Performance Indicators) should follow the SMART criteria: Specific (Clarify the metric to improve); Measurable (The metric should be quantifiable, i.e. a benchmark should be defined to visualize progress); Assignable (The indicator must be assigned to a certain area); Realistic (The goal set should be practical, given resources); Time-related (It should be specified when the results are to be viewed).

Additionally, effective performance measurement, as defined by Parker (2000), depicts results and not the process, has normalized metrics that can be used for benchmarking, is practical and easily understandable, provides an ongoing self-evaluation, and uses reliable criteria;

2.3.2 Logistics and Warehouse KPIs

A paper by Piotrowicz and Cuthbertson (2015) presents a study of supply chain performance measurement and classifies the top-rated among the most common KPIs according to different dimensions: Social, Economic and Environmental. Their findings are summarised in Figure 2.1, and the most significant are detailed next.

Sustainability		
Social	Economic	Environmental
<i>Health and safety</i>	<i>Quality</i>	<i>Emissions</i>
1. Number of accidents (employees)	1. On-time delivery	1. Level of CO ₂ emission
2. Work conditions	2. Customer satisfaction	2. Level of CO ₂ emission from transport processes
3. Number of accidents (non-employees)	3. Order fill rate	3. Level of CO ₂ emission from infrastructure
<i>Noise</i>	<i>Efficiency</i>	<i>Natural resources utilisation</i>
1. Noise volume	1. Distribution costs	1. Energy use
2. Time of noise emission	2. Total costs	2. Water consumption
3. Noise emission in urban areas	3. Transport costs	3. Energy consumption/revenue
<i>Employees</i>	<i>Responsiveness</i>	<i>Waste and recycling</i>
1. Employees skills	1. Stock-outs	1. Level of waste
2. Employees satisfaction	2. Product lateness	2. Level of products recycled
3. Per cent of labour cost spent on training	3. Lead time	3. Level of products reused
	4. Forecast accuracy	

Figure 2.1: Most important supply chain KPIs (Adapted from Piotrowicz and Cuthbertson (2015))

The authors mention that the key metrics are in the economic dimension: Quality, Efficiency, and Responsiveness, and concluded that the essential individual metrics are On-time Delivery and Customer Satisfaction (Quality), Total Costs and Transport Costs (Efficiency). Regarding specific warehouse metrics, a study by Rahman et al. (2021) analyses and ranks the most important KPIs and finds that Warehouse Management System, Storage Space Utilization and Throughput are the most relevant for measuring and improving productivity. Finally, using WMS provides performance measurement metrics of the warehouse, such as stock management and order fulfilment (Ramaa et al., 2012).

2.3.3 Maintenance KPIs

The fundamental role of maintenance is to decrease or eliminate failures and resulting outcomes (Muchiri et al., 2011). Correct maintenance of the various equipments that constitute the automated warehouse is then crucial for the performance of the operation.

Ahuja and Khamba (2008) defines three types of Maintenance: Corrective: Repair performed exclusively after the equipment fails or stops or after a substantial drop in performance; Preventive: Based on the probability estimation of equipment failure within a time interval, this action follows a planned schedule. Actions performed can be simply cleaning, replacing or lubricating equipment parts; Predictive: Diagnostic techniques used to assess indicators such as temperature, noise, vibration, lubrication, and equipment corrosion.

Muchiri et al. (2011) depicts the following maintenance metrics as essential: Number of failures; Failure/Breakdown occurrence; Availability: Mean Time Between Failures (MTBF) and Mean

Time To Repair (MTTR); Overall Equipment Effectiveness (OEE) and components (Availability, Performance, Quality).

OEE is described by (Ahuja and Khamba, 2008) as a tool that measures types of losses during production and identifies areas of improvement. Six primary losses are identified in Figure 2.2 as well as the calculation of this indicator:

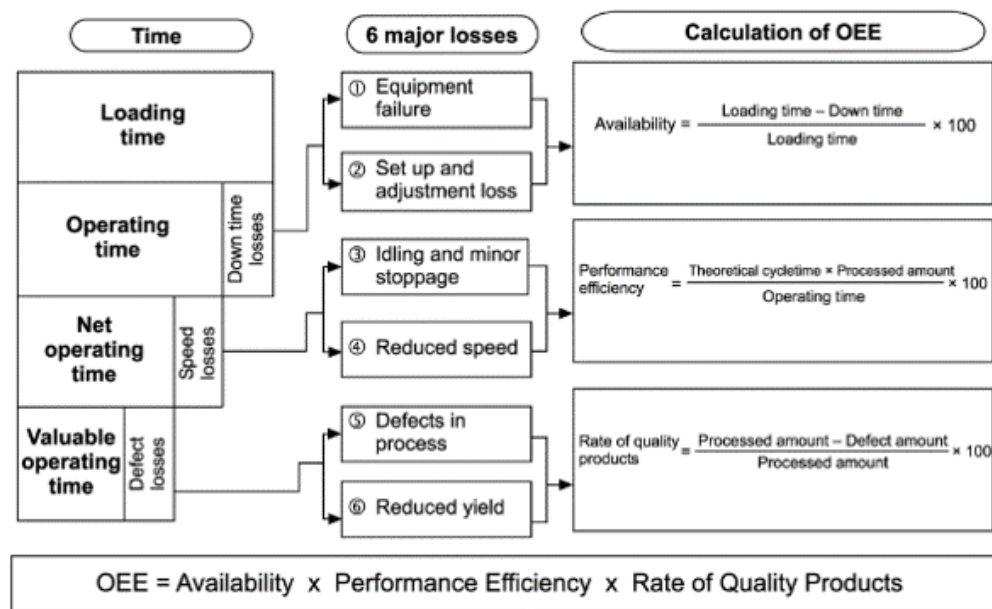


Figure 2.2: OEE calculation (Adapted from Ahuja and Khamba (2008))

2.3.4 Visualization of KPIs

Visualising the Key Performance Indicators of a company in a dashboard leads to an effective way of regarding deviations between results and objectives, identifying problems and studying their causes.

Decision-makers are able to make quicker and more accurate observations by visualizing them with the appropriate techniques and characteristics. The user experience must be taken into consideration when designing dashboard displays to preserve efficiency and show all the crucial information on a single screen. It emphasizes adaptability, validity, dependability, understandability, and simplicity (Piela, 2017). A bad interface design may have an adverse effect, while a strong information design will make it simple to find supporting information and effectively explain vital facts (Brath and Peters, 2004).

2.4 Gamification Overview

Gamification has been a topic of increased attention and popularity for the last few years (Figure 2.3). By 2025, the market size is expected to have a compound annual growth rate (CAGR) of 27.4%, rising to \$30.7 billion (MarketsandMarkets, 2020).

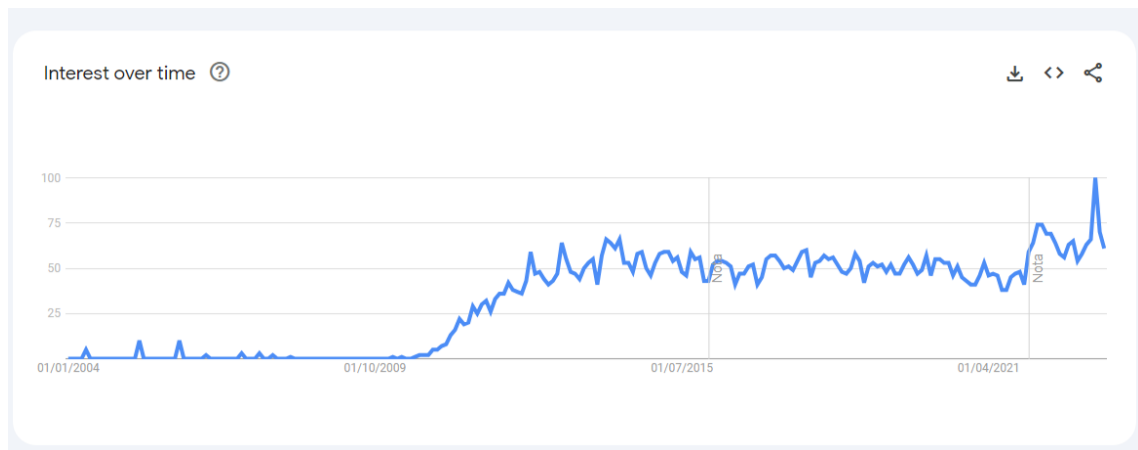


Figure 2.3: Gamification research (Adapted from Google Trends)

2.4.1 Definition

The most common and broadest description is given by Deterding et al. (2011) as "the use of game design elements in non-game contexts." The "game" aspect involves a goal that must be accomplished, rules that specify how to reach it and a feedback system that tracks progress. "Design elements" are to separate gamification from serious games, they involve anything that can be found in games and have significant meaning: badges, leaderboards and levels. Finally, "non-game contexts" means a widespread area. Gamification has been used in diverse areas. The literature on gamification has been mostly focused on education, crowdsourcing and health (Hamari et al., 2014). Hamari et al. (2014) also mention that the effects of gamification strongly rely on the environment in which it is applied to and the people who use it.

Typical elements involve Points; Badges; Leaderboards; Progression; Status; Levels; Rewards and Roles (Seaborn and Fels, 2015; Koivisto and Hamari, 2019). Some of the roles that these elements serve are to provide feedback, achievements, a sense of progression and self-expression (Richter et al., 2015).

Ryan et al. (2006) defines Self-Determination Theory to explain why games work. This concept defines the needs of Competency, Relatedness and Autonomy as the basis for human intrinsic motivation, and game mechanics appeal to them, since the sense of progress gives a feeling of competency, and games usually involve interacting with others and having choices. These motivational resources lead to engagement which in turn leads to performance.

Gamification has been proven to work in a multitude of sectors: Interactive e-learning, and visually engaging content, that use quizzes and reward progress to motivate knowledge retention; Fitness and health apps where people can set goals, track their progress and compete with friends, which leads to motivation; Reward programs of many retail businesses that encourage repeat purchasing and customer loyalty by earning a free meal (for example) after a certain amount of times and Marketing brands that use gamified challenges and interactive campaigns to attract and retain clients. The vast areas of applications show that the use of gamification enhances motivation and leads to desired outcomes such as changed behaviours or develop skills.

2.4.2 Effect of Rewards in Motivation

Regarding the use of the game element of rewards for motivational benefits and changing behaviors, they are a common feature of Gamification. A reward can enhance motivation when it is linked to achieving progressively demanding criteria (Pierce et al., 2003). Digital achievements can have an effect on motivation and performance, if designed correctly and in low quantity, they increase motivation and actually outperform classic goal-setting strategies (Groening and Binnewies, 2019). Virtual rewards can motivate people enough due to feedback and achievement feelings.

Concerning physical rewards, extrinsic motivation with a financial incentive may help adopt a new behavior but the individual might focus only on the reward component and after it is removed, the source of motivation is lost (Pierce et al., 2003). However, Deci et al. (1999) notes that these types of incentives may reduce intrinsic motivation due to their controlling nature, so they might not be effective in improving motivation in the long run. Nicholson (2015) has a similar view: Rewards have been used for short-term solutions where participants aren't motivated, and they can be effective but they might reduce intrinsic motivation and long-term engagement. The danger with this type of gamification comes when the goal is to create long-term change. In addition, Deci et al. (1999) states that the rewards have to be adapted to the users' needs and preferences as well as the gamification system. It is deemed essential, then to balance the use of rewards with intrinsic motivation factors to form a sustainable experience.

Regarding the use of rewards in CIN's operation, the conclusion is that it should be approached with caution, given the negative effects of extrinsic rewards on intrinsic motivation. Other factors have to be taken into account such as feedback and recognition. The design of the rewards has to be aligned with individual preferences as well as the gamification app. The success of any gamification system depends on how more closely the goal of the system is aligned with the goal of the players (Kim, 2015) and the characteristics of the environment (Morschheuser et al., 2017).

2.4.3 Gamification in Warehouse Environments

Gamification has been used in work environments to increase productivity and engagement of employees. Cardador et al. (2017) defines work gamification as a way of measuring performance using technology for real-time access to performance information and make tasks more enjoyable. By giving employees immediate and visible feedback about their performance compared to a standard, work gamification might encourage workers to change their performance.

There have not been many warehouse-related applications of this concept. Hense et al. (2014) mentions that staff motivation and high turnover rates are recurrent problems in intralogistics, due to the challenge of fulfilling dozens of correct orders under time constraints and that order picking is usually done by low-paid workers. In repetitive tasks, such as picking orders, motivating individuals is not easy, and gamification can help with that by converting tasks into games. An article by Bahr et al. (2022) presents different perspectives of warehouse managers in the UK on gamifying warehouse activities. They suggest that gamification can be applicable, with the goal

of increased engagement and productivity, but there are also obstacles such as the efficacy over time, the need for careful planning and ethical considerations, and to ensure the system is fair for all players.

Regarding rewards, a survey by Ponis et al. (2020) said that the supervisors preferred the competition approach of rewarding the best employees, and the pickers prefer the completion approach, i.e. individual rewards based on achievements compared to standards.

Finally, Bräuer and Mazarakis (2019)'s study of the test of leaderboards and badges to assess the effect on motivation and performance of warehouse workers showed that leaderboards can harm the feeling of relatedness, thus reducing motivation, if competition is the main focus instead of cooperation.

Gamified solutions must be then carefully thought out and fit with the company's culture and strategy. Adding a gamification system is a difficult balance between keeping employees engaged without adding stress and they don't solve existing problems such as poor culture and team conflicts (Hammedi et al., 2021). To conclude, the summary of the literature findings is that gamification has the potential to make order-picking operations more enjoyable and motivating. However, to be successful, it requires careful planning and adaption to the workers needs and motivation and to be continuously evaluated, according to the warehouse performance objectives.

Chapter 3

Current State Overview

This chapter first presents an overview of the distribution center's layout and the different logistics procedures that occur. Afterwards, a detailed examination of the automated warehouse's structure and operations is done, where the project is based, with an emphasis on the current state of the picking operation and performance indicators. Finally, a multi-week sample study of equipment stops is examined in detail, with maintenance indicators estimated, and a thorough identification and breakdown of the issues that impact this sector's performance are provided.

3.1 Overview of the Distribution Center

The layout and a brief description of the DC operations in each area are presented in Figure 3.1.

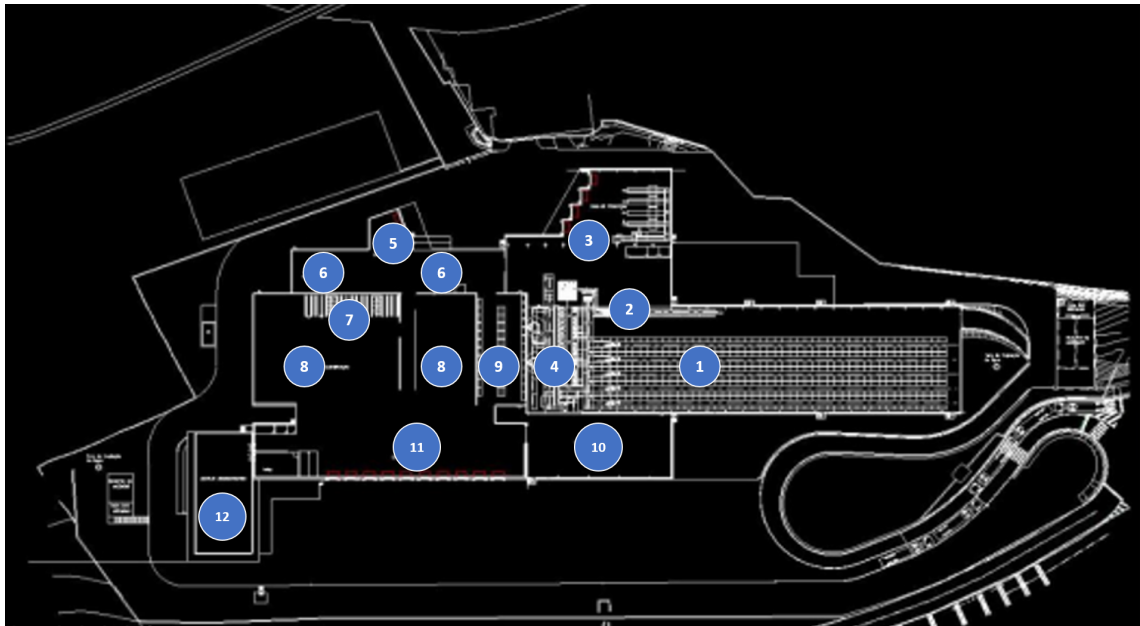


Figure 3.1: Layout of CIN's Distribution Center, adapted from ULMA internal file

1. Pallet Warehouse: Detailed in Section 3.2

2. Miniload Warehouse: Detailed in Section 3.2
3. Reception Docks: Detailed in Section 3.2
4. Picking Zones and Exit Conveyor: Detailed in Section 3.2
5. Immediate Expedition Area: Cross-docking area
6. Reverse Logistics: Return of products
7. Drive-in: Storage area
8. Exportation Area: Where international orders are prepared in advance (usually two weeks)
9. Conventional Warehouse: Traditional storage and picking area, mostly used for products with non-compatible dimensions and/or weight with the AW specifications
10. Color Tuning/Production by Colormix Area: Where the base paint of a product is tainted with a machine into a specific color
11. Expedition Docks: The final phase in the order process workflow, in which the pallets are stored on the dock of the corresponding route, and the orders are verified to be complete and meet the required quality standards
12. Offices

The AW area and system in total comprehends (1), (2), as well as (3) and (4), and it is made of two levels (the second 3.5 m above ground), six automated stacker cranes, roller conveyors and two elevators, all of which serve to make the pallets move around the reception, storage, picking and exit areas.

3.2 Automated Warehouse Layout and Operations

In this zone, several operations are performed, that form a flux of the product journey in the AW: Reception, Storage, Picking and Plastic wrapping of pallets. The layout of the floors of the AW is displayed in Figure 3.2.

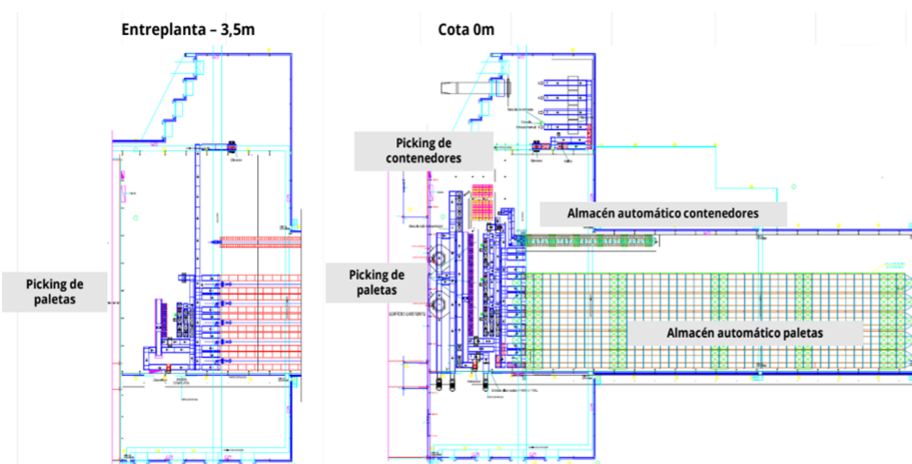


Figure 3.2: Top and Bottom floors of the automated warehouse, adapted from ULMA internal file

3.2.1 Reception

This area has four docks, where trucks unload products from internal and external suppliers and others are loaded for internal dispatch with products and/or pallets to return. Products are usually received during the day shift, although it periodically happens during the night shift as well. Products can be stored in the automated pallet or miniload warehouses, or other storage areas in the distribution center. The operation performed here is the same for both automated storage areas and its complexity only depends on the origin of the products to be stored:

- Internal suppliers (CIN plants):
 - Put pallets directly from the arrival truck into the entrance of the automated warehouse;
 - Scan the check-in label placed by the internal supplier (that displays information about the lot, expiration date of the product and intended storage area) to register the entrance of the product in the software, and automatically assign a destination.
- External suppliers:
 - Unload the pallets;
 - Verify if the product and quantities received correspond with the information in the transport guide and delivery note. The first has to contain information on the address, number of pallets and the supplier, and the second must have the supplier indication, order number, description of products and quantity of pallets;
 - Move the products into CIN pallets;
 - Record on the system all the information, to update stock levels and automatically assign a location to the product;
 - Place the pallets at the entrance of the AW.

Finally, regarding the operation in the entrance area (Figure 3.3), the process is sketched in Figure 3.4 and detailed as follows:

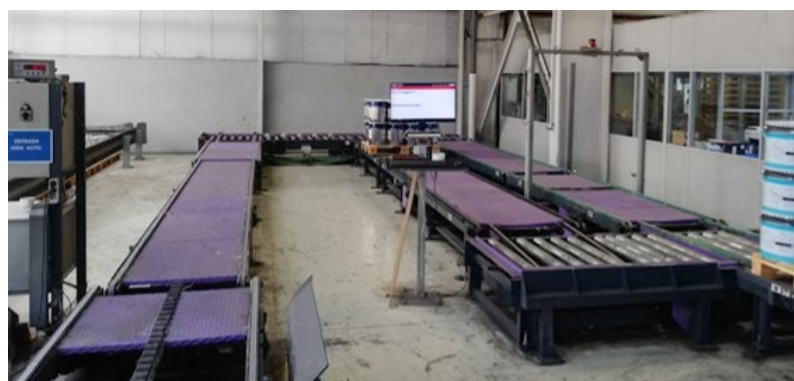


Figure 3.3: Entrance area of the AW

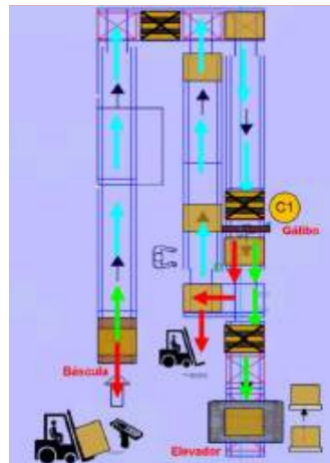


Figure 3.4: Entrance operation, adapted from ULMA internal file

- The operator places the pallet in the entry conveyor using a forklift, where it is weighed, compared with a maximum value and continues if it doesn't exceed the tolerance limits. Before the load enters the elevator and goes to the top floor by elevator to be stored, there's a control post (C1) in place, that ensures that safety standards are met by detecting errors;
- Errors can occur because the material exceeds the width or depth of the pallet or height limit of the storage racks. If an error is detected the pallets are rejected and moved to another conveyor where the operator can analyse and fix the issues and guarantee the cans within pallets are properly positioned and stacked;
- In case there is no error signaled, the load moves to the elevator and proceeds in the conveyors (1) and (2) into the storage area.

Figure 3.5 displays the layout of the top floor part where the pallet moves to enter the automated warehouse.

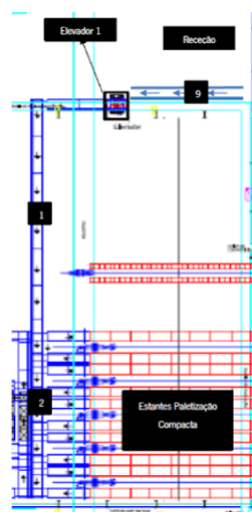


Figure 3.5: Layout of the reception conveyor on the top floor, adapted from ULMA internal file

3.2.2 Storage and Inventory Management

The assignment of storage location is done by an internal optimization algorithm that follows a rule connected to product rotation in each subsystem, it corresponds to an ABC classification (Figure 3.6).

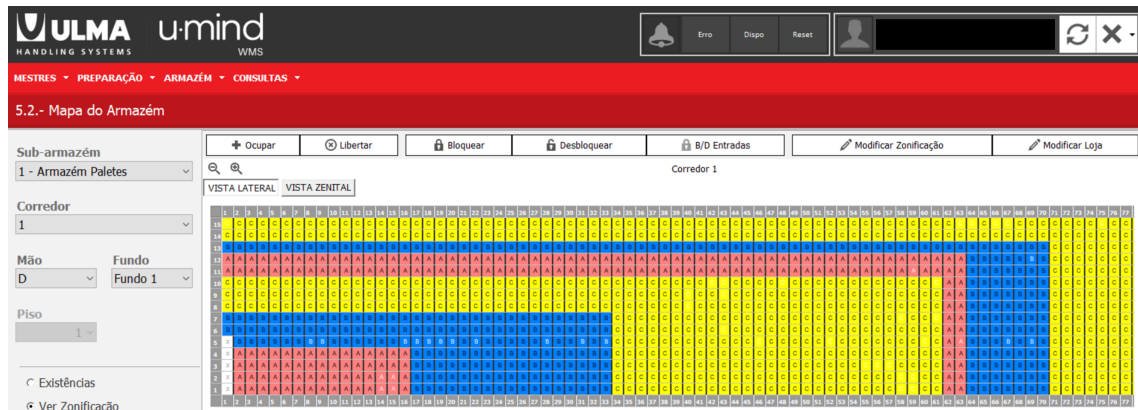


Figure 3.6: Screenshot of the stock management system in the pallet warehouse

Pallets entering the system are always placed in the nearest available space in the corridor, with high-turnover products positioned in the first free racks and low-turnover products in the last free racks.

Regarding products intended for the miniload warehouse, they first enter the pallet warehouse and then are moved to an area near the miniload warehouse entrance where an operator manually takes the products from the pallet and places them on containers, registers in the system and then the empty pallet is stored. The products stored in this system are lightweight/small products (such as auxiliary materials like brushes) and the allocation of storage in this system is done at random if there is an empty space available.

At all stages of the process, the WMS (Warehouse Management System) has information on the location and unique code of each pallet and respective SKU, ensuring a permanent inventory system. The circuit of pallets within the warehouse is rigorously controlled by the WMS (Warehouse Management System):

1. Orders are launched on the company's ERP (Enterprise Resource Planning) software and then sent to the WMS;
2. This makes the automated stacker cranes retrieve the pallets of the items that form the order and deposit them on the conveyors to move the pallet to the allocated picking post;
3. In addition to the ABC class categorization, the algorithm of the products to be picked also has one additional criterion: FEFO (First Expired First Out), where products with the earliest expiration dates are prioritized.

Every stacker crane of the pallet warehouse (identified on Table A.1 of Appendix A, commonly referred to as TE1-TE5) has an entry and exit conveyor at the entrance of each corridor and there

are 4 conveyors that make the pallets travel along the warehouse, their functioning is displayed in 3.7.

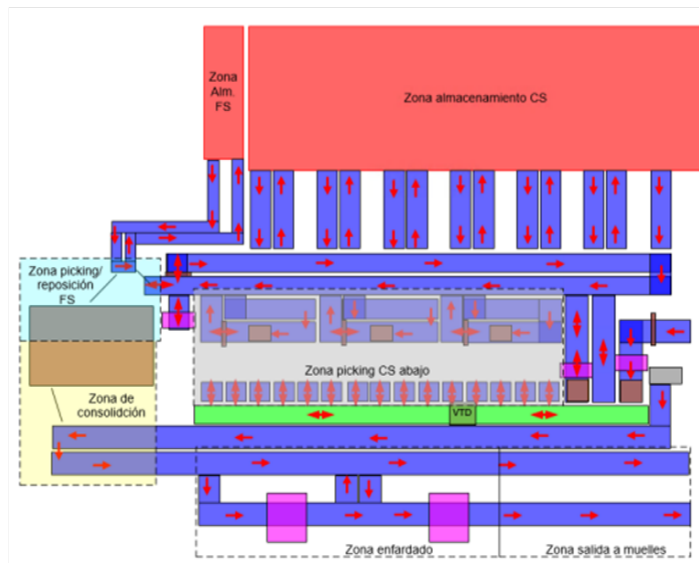


Figure 3.7: Sequence of pallet movements on the AW conveyors (ULMA internal file)

3.2.3 Order Picking

The picking zone is made up of five picking posts in total, one for the miniload system, which consists of three rows with eleven containers each, and four for the pallet system: three on the bottom floor and one on the top floor (the procedure on both floors follows the same logic). Every picking post in this system has five tables, which means that a worker can work simultaneously on five different orders. Each order is destined for a route that is part of a larger group of routes.

There are commonly four dedicated workers assigned to this sector and distributed along the miniload and picking area (usually three on the bottom floor and one above). The upstairs post doesn't work at all times. This occurs when the order plan workload doesn't justify having 4 posts working, when there is not enough available personnel for all the posts or even when there is a machine malfunctioning that prevents products of one corridor from being retrieved, affecting the throughput of the warehouse. This way, the supervisor usually chooses to close this post and direct the machines to move items to the others.

3.2.3.1 Pallet Warehouse

There are three types of picking in the pallet warehouse:

- **Full Pallet:** Corresponds to batch picking, which occurs when the amount of units requested matches the quantity of a full pallet of the product. This pallet doesn't need an operator's intervention and moves directly to the exit conveyor, through the top floor by an elevator that transports these full pallet loads, as well as the picking pallets on the top floor's picking post.

- Reverse Picking: If the number of units required is superior to 70% of a full pallet, a pallet of that product will be placed directly on the picking table, and the worker has to remove the surplus and put on an empty pallet on the picking post to go back to the warehouse.

To illustrate, considering a pallet of 33 units of 15-litre cans (maximum capacity), if there's an order for 25 units of that product, it's more effective and requires less effort and time, for it to be placed on the picking table instead and the operator to remove the 8 units than for it to follow the normal process and pick 25 units.

- Discrete Picking: This is the normal picking situation and its main functioning is displayed in the following swimlane (Figure 3.8) and detailed next.

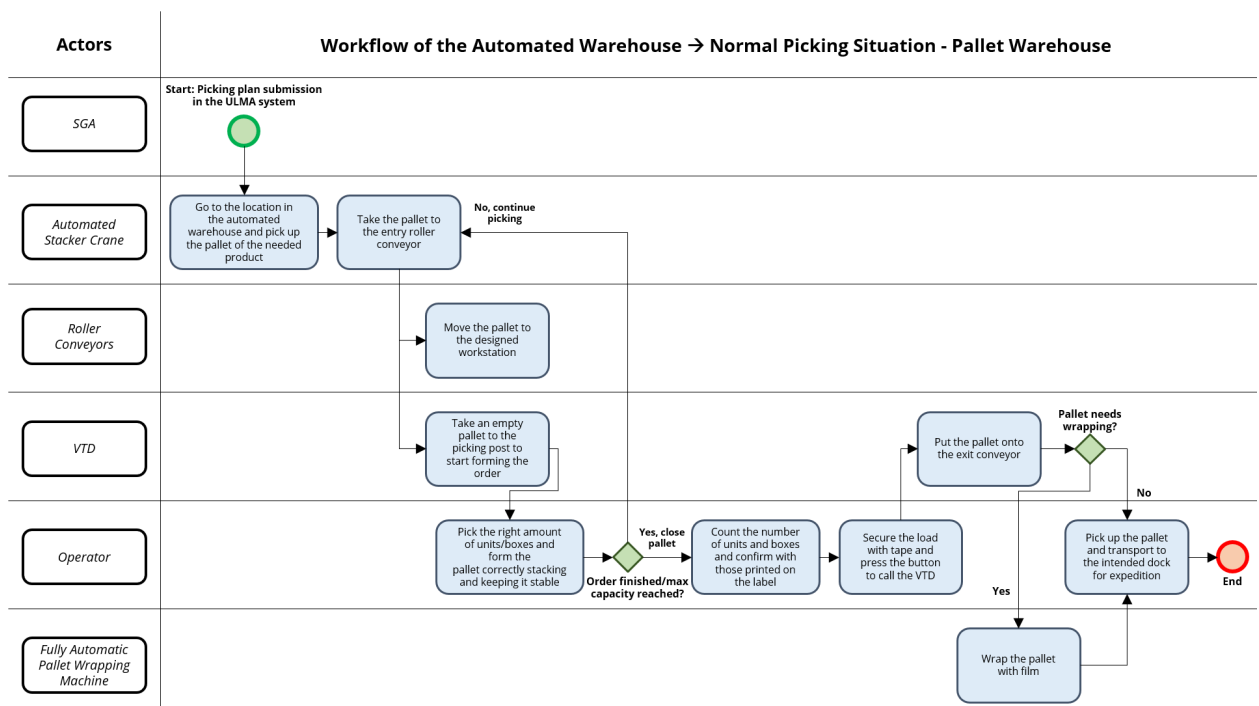


Figure 3.8: Swimlane of normal picking operation in the pallet warehouse (Personal elaboration)

The products to be picked are categorized as units (products picked by unit) or boxes, this typification is done on products that are usually lighter/smaller, imposing a minimum and multiple amounts of sales quantity this way, therefore, enhancing the efficiency of storage and machine utilization (e.g. considering a box containing 6 one-litre cans of one product, a client can only order a minimum of 6 units of that product, if he wants more then he has to buy 12 or 18 units, and so on. It's not efficient to store, retrieve and pick fewer units of this type of product).

When the pallet arrives at the picking station, the software displays on a computer the intended destination table, necessary units or boxes to pick, the unique code of the product and the remaining units on the pallet after it is picked. If for some reason these quantities don't match, the operator has to check if he has separated more or fewer units than supposed to, and if not, he has to call all pallets of that SKU to this post to find out what went wrong. This works as a tool for keeping permanent inventory functioning and tracking potential picking errors. Figure 3.9

displays the information of 8 units of one product that are destined to be picked at the middle table of the picking post.

Confirmador PICKING													
 <F5> Confirmador		 <F9> Refrescar dados		 <F2> Inventário		 <F3> Desabilitar Pesagem 1 vez		 <F7> Petição Peso		 <F6> QUASE - Saída		 Reimprimir	
Matricula	Grupo	Cód. Artigo	Desc. Artigo	Lote	Empilhabilidade	Data Cadastro	Quantidade	Disponível					
1000000000499	1	ART104	Artículo 04	101144 4		16/07/2022	40	32					
☐ No enfiador													
220													
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This confirmation is a crucial part of the order process because it is the last time the quantities of the products will be checked before leaving the warehouse, after which, picking errors will reach the client. Common examples of these are orders with more, fewer or faulty units, although damages can occur during transportation it's important to continuously verify the quality of the units when picking.



Figure 3.11: Finished pallet secured

Finally, a machine (VTD) transports the pallet from the table to the exit conveyor and goes to pick up a new empty one to continue the order or begin another, if there is one. Regarding ergonomic conditions, the workers have mechanical tools that help them carry the loads, noise protectors and gloves for picking up the products.

3.2.3.2 Miniload Warehouse

Since the workload in this container warehouse is smaller, both in the size of products and demand (in 2023 the total picks constituted 16% of the total automated warehouse picks (Section 3.6 Statistic Analysis of Picks)), it is a much faster and simpler process than the one previously detailed. Likewise, it involves a pick-to-light system although with slight differences:

- Picking is only done of units and not boxes (if a product is inside a box, the operator has to retrieve the necessary units or pick the box if the amount corresponds to the units needed);
- The operator has to manually place a container in the corresponding location where a DPD is signalling with the necessary quantities;
- When the order is finished or the full capacity is reached, units must be counted and the container is then manually pushed to the consolidation post.

In this area, two distinct processes occur:

- Manual consolidation: For orders with only products from the miniload storage, the worker has to manually place an empty pallet on the conveyor and in there the products that were picked in the miniload post;
- Automatic consolidation: For orders with products from both systems, the worker must add the necessary units from the miniload to the picking pallet and validate the definitive number of items in the finished pallet.

3.2.4 Pallet Wrapping and Exit

Every pallet follows the same exit conveyor (8), next to the elevator, and if it requires plastic wrapping they are moved to the conveyor that leads to exit S2 to be processed. If this procedure isn't needed they can leave through S1. At the end of the process an operator moves the pallet with a forklift to the correspondent dock for expedition. Figure 3.12 shows this layout in detail.

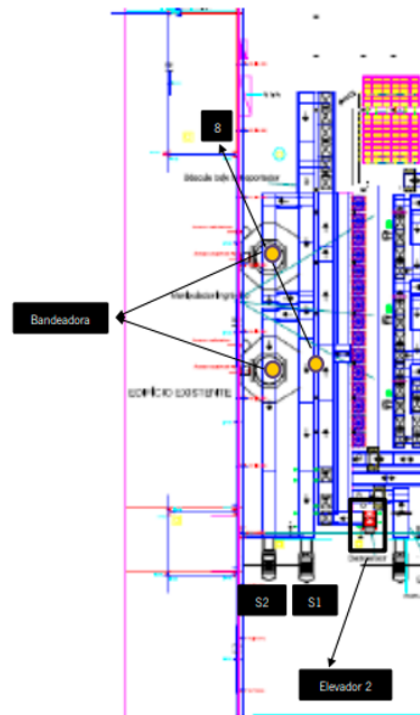


Figure 3.12: Detailed layout of bottom floor, adapted from ULMA internal file

3.3 Schedule and Functioning

This sector functions on two different shifts with meal and breaks specific schedules presented in Table 3.1, as well as bathroom breaks coordinated between the workers. Both shifts have a manager and supervisor, responsible for operations.

Table 3.1: Shift schedules

Shift	Schedule	Meal Breaks	Snack Breaks
Day (T1 or TD)	08-17h	12h-13h 12h45-13h45	09h30-09h45 15h30-15h45
Night (T2 or TN)	17h-02h	21h-22h	18h30-18h45 00h30-00h45

The out-of-sync meal time during the day shift allows the automated warehouse to keep operating, and in this 45 min period, normally workers from other sectors go to work at the picking

section. Finally, during periods of increased demand and workload, a "bank of hours" system occurs, where the operators work from 6h to 17h on T1 and from 17h to 4h on T2.

Consequently (in theory) the automated machines operate continuously during both shifts, if there is the need for pallets to be circulating, and they only stop from 12h45 to 13h. In reality, there are highly frequent equipment stops (and even total failures) or jams in the roller conveyors due to the wear of their mechanical components, which often force the workers (who know how to handle the machines) to leave the picking posts to reposition the pallet and restart the machines (this procedure is detailed in Section 3.5 Maintenance Issues).

At the beginning of each shift, there is a Daily Kaizen meeting with all the workers to involve them in the daily activity plans of the sector, discuss important issues or events (like machine failures or frequent stops), show the indicators of the previous day and compare with the goal (detailed in Section 3.4 Key Performance Indicators) and finally, provide an opportunity for the workers to give suggestions of improvement measures (continuous improvement system).

3.4 Key Performance Indicators

The performance measurement of the picking operation is done by tracking these metrics: Service Level, Productivity and Quality.

- Service Level:

- PEC ("Perfeito" - "Em Tempo" - "Completo"): Perfect orders (no mistakes), delivered on time and fully;
- OTIF (On-Time-In-Full): Order lines delivered on time and in full.

Two indicators categorize the service level of the company - PEC and OTIF - and both measure the ability to deliver the complete order on time and with no item faults. The first evaluates the whole order and the second considers each line of the order (every line corresponds to each product's quantities that constitute the order). So, for orders with multiple lines, if there's a fault (due to a delay of delivery, units not being delivered or defective items) in one order, for OTIF only the specific line is affected, and for PEC, the whole order is impacted.

Therefore, the more precise assessment of the service level performance is OTIF. Its total objective is 95% and delivery delays are commonly the component that negatively influences this indicator. In addition, tracking each component allows for the identification and correction of the causes of the failures.

- Productivity:

- Pick Rate (number of picks/hour/man);
- Total Picks (Full Pallets + Miniload Picks + "Normal" Picks).

A pick corresponds to an order line in the pick plan, it's when the operator separates the necessary items and presses the button. The quantity of items, which can differ greatly (Section 3.6 Statistic Analysis of Picks), is not taken into account and neither is the volume or weight of the items (requires different effort).

The fundamental productivity indicator of the automated warehouse is the Pick rate - the number of picks per hour and per man - with the current goal of 39. Other indicators are measured and mentioned in the daily meeting, such as the total picks, of which some are full pallets and the rest are picks from the miniload system. The goal for total picks of each shift is estimated to be around 1250, corresponding to $39 \text{ picks/hour/man} * 4 \text{ posts} * 8 \text{ hours}$.

The productivities of each shift are calculated (and stored on a file) by the respective supervisors at the end of each day using the total picks and an estimation of the time each worker spent picking (it's not an exact value, the supervisor discounts some time if the machines were unavailable thus preventing the operator to do his work). The productivity of the whole AW is calculated through the total number of picks divided by the total number of hours worked, in both shifts.

The following factors have an impact on productivity:

- Different daily picking plans and demand: It can be said that the business is seasonal (Section 3.6 Statistic Analysis of Picks) since some periods require higher workloads. In addition to this, on days when there is more demand for full pallets or items from the miniload, productivity tends to increase because the first ones don't need manual intervention and the second ones are easier and faster to manipulate;
- Pallets entering the AW: Stacker cranes have to store them which prevents them to move loads for the picking posts;
- Exit conveyor gets full: Happens when there are a lot of pallets in the exit conveyor waiting to exit, it prevents the tables from picking of being placed there and so the picking operation stops;
- Frequent equipment errors: This is an indicator that isn't measured and that strongly affects productivity because stops happen randomly and operators have to leave their normal picking operation and go correct the errors. Furthermore, if these stops aren't fixed rapidly, using the stacker cranes as an example (where it is most common), products of that corridor won't move to the conveyors, which results in productivity losses. A detailed study and analysis of stops are described in Section 3.5 Maintenance Issues.

Total picks and productivity for both shifts are written and a graph is drawn (with the reference line of 39 picks/hour/man) with a monthly timeline, and it is exhibited on the Daily Kaizen board (Shown in A.1 of Appendix A).

- Quality: Delivery Error Rate.

Concerning delivery error rate, it measures the errors in relation to the total deliveries, and this indicator distinguishes between external (which occur after the goods are sent, such

as damage in the cargo) and internal errors, considering both the performance of suppliers and the process of the automated warehouse, with the purpose of continuous improvement. Nowadays, the target is 0.8% of all orders, considering the total errors, regardless of the origin. When this goal isn't met it is mostly due to external factors, but errors in picking still happen and should be reduced.

Lastly, daily occurrences such as items damaged/spilled over due to accidents (such as equipment malfunctions) or lengthy machine breakdowns (with the necessary interventions from Maintenance) are mentioned but not continuously tracked. A detailed description of the Maintenance operation and issues are given in the following section (3.5 Maintenance Issues).

3.5 Maintenance Issues

There are three kinds of maintenance interventions performed in the AW: Condition-based, corrective and preventive. They can be conducted by CIN's Maintenance department, which is not located in the DC but at the factory, and by the external supplier of the warehouse (ULMA Handling Systems), located in Spain.

ULMA provides only preventive maintenance and spare parts, and the department intervenes to conduct corrective maintenance. The interventions from 2018 to 2020 are displayed in Table 3.2 (and data from the most recent years follows a similar trend).

Table 3.2: Maintenance interventions per type

Maintenance Interventions	2018	2019	2020
Hours of breakdowns	818	769	480
Total Picks	706 324	722 131	725 500
% Condition-based Maintenance	60%	72%	78%
% Corrective Maintenance	30%	19%	13%
% Preventive Maintenance	10%	9%	9%

The number of preventive maintenance interventions is quite low, given the impact and frequency of equipment stops, and there are recurring interventions of the other types, a factor that remains similar currently. In these years, the machine malfunctions were registered manually by the operators on paper and then converted digitally by the supervisor, with an estimation of stop times (using the format depicted in Figure B.1 of Appendix B) where the length, location and type of errors (stops or breakdowns) were registered.

Each week detailed maintenance reports with information on breakdowns were made, and the availability rate and OEE for the whole automated warehouse were calculated. With the increase in the number of stops and volume of sales, this registry stopped being done in 2020 due to the high time investment and the need to focus on more relevant procedures.

3.5.1 Machine Error Details and Correction Process

The automatic function of the stacker cranes retrieval of pallets from the warehouse consists of: going to the rack in the warehouse where it is located, positioning correctly in front of the location with a detector, picking up the pallet placing the forks underneath it, moving them up and then back to center it in place, and finally travelling to the picking conveyors and deposit the items. Sensors present on the stacker crane stop its movement if anything unusual is detected (details on the type of errors are given in 3.5.2.1 Types of Errors).

These stops are detected by a sound and visual signal (permanent orange light), near the ceiling of the ground floor, at the entrance of each corridor (e.g. if the light in front of aisle 5 signals, it cues the operators immediately that there is an issue on TE5).

To correct the issue, an operator must access the control panel of the respective stacker crane (located next to the picking posts) with a key, and with a piece of equipment placed nearby (shown in Figure B.2 of Appendix B), he sees the type of error and the exact horizontal and vertical location of the pallet.

Then, with the key and the reader, the operator moves into the corridor and goes to the stacker crane to correct the issue, during which, the light starts blinking.

Typically it is done by manipulating the pallet from the ground with this equipment and positioning it correctly, although occasionally they have to be moved to the ground and the operator has to fix the items in the pallet. After this, he returns and plugs the key into the control panel, and rearms the machine by pressing a button.

In the case of the VTD equipment, there is a red visual light that activates if there's a malfunction. In addition, as mentioned, jams in the movement of the roller conveyors can cause the pallets to hit somewhere and turn on the conveyor and the operator has to act fast (if he notices) to prevent the cans from falling and spilling.

Given the focus of the project in this area, to get a good understanding of the operation and evaluate how these occurrences impact the picking activity, a multi-week close monitoring of this activity resulted in the categorization of the most common errors, discovery of root causes and estimation of key maintenance indicators: Availability Rate, OEE, MTBF, MTTR.

3.5.2 Manual Study of Stops and Maintenance Indicators

To collect the needed data, using a similar template as the previous "system" (Figure B.3 of Appendix B), a manual record was done in three instances: Time (hour:minutes) when the machine stopped, when the operator moved to go fix the error and when the correction finished. The origin and type of error were also registered, with the information just as displayed on the handler.

During a 31-day period, 347 errors were noted, on an average of 2h12min spent daily in the picking posts, with a total analysis time equivalent to the duration of 8.5 total shifts. Other details of the duration of the study are shown in Table B.1 of Appendix B.

3.5.2.1 Types of Errors

A FTA (Fault Tree Analysis) is used to successfully specify the cause(s) of system failure to reduce risks before they materialize (Hessing, 2020). A categorization of the most frequent errors for each equipment of the AW is shown in a FTA in Figure 3.13.

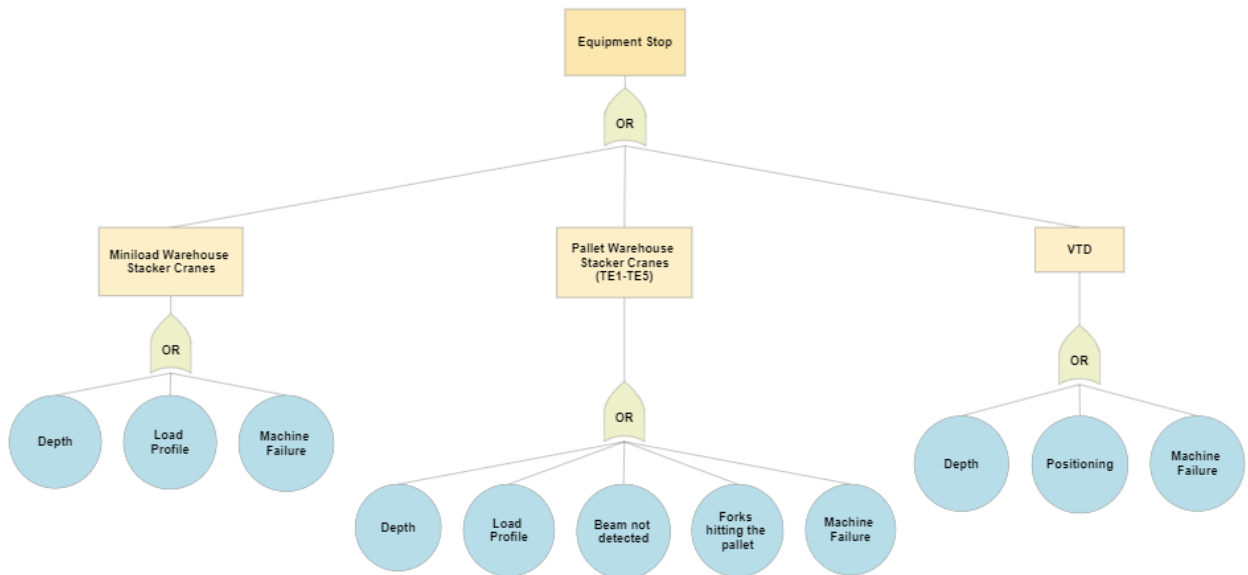


Figure 3.13: Fault Tree Analysis of most common machine errors (personal elaboration)

Furthermore, using feedback from operators and supervisors, a clear categorization of each type of error was accomplished through the discovery of the respective causes:

- Depth: Pallet doesn't center correctly in the stacker crane when it picks it up, so it exceeds the depth boundaries set by detectors on each corner;
- Load profile: Loads with units exceeding the limit of the pallet. To illustrate, having just a can strap or a cardboard a little off the boundaries of the pallet activate a sensor and stops the stacker crane movement;
- Beam not detected: Sensor doesn't detect the rack where the pallet is supposed to go to, because of dirt or reflection light or other reasons which are difficult to identify from the ground;
- Forks hitting the pallet: Pallet slightly tilted or with damaged piece of wood sticking out, preventing the forks of the stacker cranes from picking up the pallet;
- Positioning: VTD laser doesn't align correctly with the pallet;
- Machine failure: The cause is not immediately known, in this case, a request to the Maintenance department for intervention has to be done as soon as possible.

As previously mentioned, the errors of the conveyors are caused by the wear and tear of the material over time, which make the pallet move more or less than supposed to or hit somewhere and turn. This usually causes informatic bugs (e.g. the pallet being in a different position than in

reality), in this case, a reset of the system needs to be done and the pallets have to be manually put back in their intended location.

3.5.2.2 Sample Analysis

The Pareto principle indicates that a significant portion of effects is driven by a relatively small number of causes. Therefore, from a Pareto Chart (Figure 3.14) it can be said that TE4 and TE5 were the equipments where the operators spent more time correcting errors.

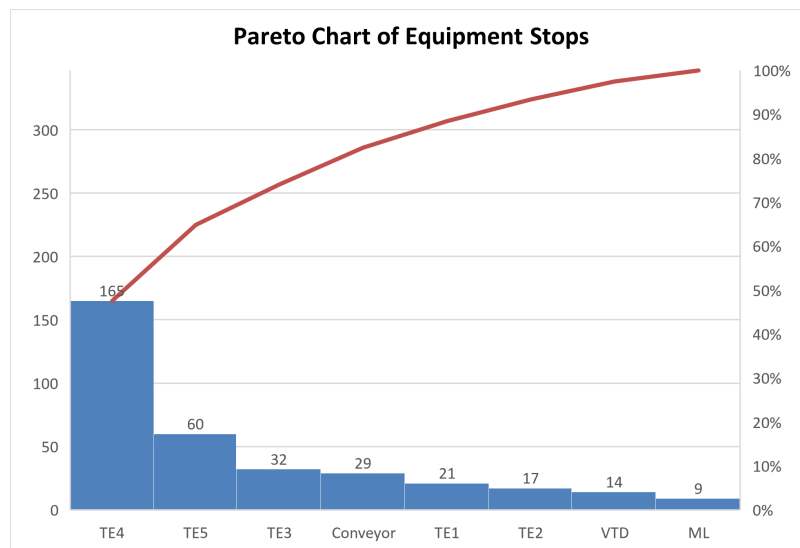


Figure 3.14: Pareto chart of equipment stops

From this sample, Table 3.3 shows a calculation of the total time of error correction and equipment stops in the 9 hours period of the shift. It is estimated that on average there are nearly 2 hours of error correction and 3 hours of machine stops per shift. TE4, the most impacted equipment, is foreseen to stop during 01h16min of this period, which means it is available 86% of the time.

Table 3.3: Estimation of total correction and stop times and availability rates

Estimation per shift	Total Correction Time	Total Stop Time	Availability Rate
TE1	00:06:05	00:12:42	98%
TE2	00:05:09	00:10:39	98%
TE3	00:08:40	00:17:20	97%
TE4	00:48:11	01:16:06	86%
TE5	00:17:37	00:31:51	94%
ML	00:05:16	00:08:54	98%
VTD	00:04:13	00:04:20	99%
Conveyor	00:19:33	00:23:11	96%
Total	01:54:44	03:05:02	-

Other relevant findings and considerations (Figures B.4 and B.5 and Tables B.2 and B.3 on Appendix B):

- Errors most frequently occur in the pallet warehouse stacker cranes (85%);
- Most common errors are depth (67%) and load profile (29%);
- Occurrence of machine total failures was remarkably low (0.34%);
- The operator takes on average 01min43s to start correcting an error and 02min49s to fix it;
- The data is influenced in some data points by errors during breaks where an operator wasn't present so the machines were stopped for longer times and these are considered outliers. Looking at the median value (less affected by extreme values), an operator takes one minute to start correcting an error and 2 minutes to fix it.

3.5.2.3 OEE - Overall Equipment Effectiveness Calculation

From 2017 to 2020, this indicator was calculated globally for all the AW (not per machine) and not in the most correct way: it only considered wrapped pallets and not all pallets that were processed and the theoretical and real cycle times were considered to be the same (2.5min/pallet). With the data gathered from the sample, and calculating the indicator for TE4 (the one with the worst availability), some considerations were made:

- Shift length: 1080 minutes (08h-02h), both shifts were considered;
- Planned downtime: 15 minutes (during lunchtime on T1);
- Unplanned downtime: 152 minutes (76 minutes per shift for TE4);
- Total parts produced: Based on the average of total picks of the pallet warehouse from January to May 2023, the daily total picks for each stacker crane were estimated at 379. This estimate only considers picking movements and not reception of products, although, from the available data, it was considered to be the most reasonable approximation possible;
- Theoretical cycle time: Obtained on a recent study (2021) from the WMS supplier ULMA of the warehouse functioning, in which they estimated the max hourly movements of TE4 to be 37. This way, the stacker crane takes 1.62 min per pallet (60 min/37 movements);
- Scrapped items: Because this process is not a production line, there are no faulty parts and thus the quality index of the parts is considered as 100%, a valid assumption because non-conformity products that might leave the AW are fairly low.

The computation process and values of each component are shown in Table 3.4.

Table 3.4: OEE components and calculation for TE4

Components	Formula	Result
Planned Production Time	Shift Length - Planned Downtime	1065
Operating Time	Planned Production Time - Unplanned Downtime	913
Availability (1)	Operating Time / Planned Production Time	85.73%
Capacity	(1 / Theoretical Cycle Time) * Operating Time	563.58
Performance (2)	Total Parts / Capacity	67.25%
Quality (3)	(Total Parts - Scrapped Items) / Total Parts	100.00%
OEE	(1) * (2) * (3)	57.65%

The obtained OEE was 57.65%, which indicates a need for improvement. When calculating this value for the remaining stacker cranes, it didn't change. This is explained because of the Operating Time component being considered on both Availability and Performance indexes, and because of the considerations made, which cause the Availability index to go up and Performance to go down (and vice-versa) and consequently, the OEE index to remain the same.

Additionally, due to the use of the average of total picks to approximate the number of pallets moved and knowing that the stacker crane movements are subject to the different daily pick plans and receipt of pallets, this index doesn't reflect a true lack of capacity of the stacker cranes. In addition, it is common that the warehouse is operating at near maximum capacity. Therefore, OEE in this case is considered not the most accurate performance estimator.

3.5.2.4 MTBF and MTTR Calculation

With this in mind, two additional indicators were calculated: Mean Time Between Failures (Equation 3.1) and Mean Time To Repair (Equation 3.2). Regarding MTTF (Mean Total Time to Failure), with the way the sample was measured and the extremely low data points of machine total failures, this indicator wasn't estimated.

$$\text{MTBF} = \frac{\text{Analysis Time} - \text{Machine Downtime}}{\text{Number of Breakdowns}} \quad (3.1)$$

$$\text{MTTR} = \frac{\text{Machine Downtime}}{\text{Number of Breakdowns}} \quad (3.2)$$

A summary table (an example for TE2 is provided in Table B.4 of Appendix B) of every period of time spent recording errors per date and the downtime and stops were made for every equipment, to obtain the total values and consider the records as a continuous study. The results are exhibited in Table 3.5.

Table 3.5: MTBF, MTTR and errors per shift calculation

Equipment	Total Errors	MTBF Global	MTTR Global	Estimated Errors per Shift
TE1	21	00:48:39	00:05:10	11
TE2	17	01:18:28	00:05:21	7
TE3	32	00:50:32	00:04:37	11
TE4	165	00:18:00	00:03:56	30
TE5	60	00:38:13	00:04:32	14
ML	9	01:12:07	00:08:27	7
VTD	14	00:53:26	00:02:39	10
Total	318	-	-	90

Interpreting the results, on average, the TE4 is estimated to function for just 18 minutes between stops and there are 90 equipment errors per shift. This lengthy analysis resulted in an estimation that is close to reality, according to the experience of the operators. It is a recurrent occurrence that significantly affects the productivity of the picking activity.

3.6 Statistic Analysis of Picks

To get a final complete overview of the process in this sector, using detailed data of every pick line of the first five months of 2023, pivot tables and graphs, ANOVA (Analysis of Variance) between shifts and correlation analysis were performed. Detailed graphics and data are presented in Figures C.1, C.2, C.3, C.4, C.5 and C.6 of Appendix C, and the main results are:

- Seasonal variance in picks: There are lower demands during winter periods. A straightforward explanation is the fact that paints dry more quickly in the summer;
- Average order line per group of routes: Measuring the complexity of the pick lines for every group of routes that CIN ships to, an average order line for less common routes (Exportation) has 50 units/boxes of a product from the pallet warehouse, and for the most common route groups (Clients/Stores) this number is around 10. This indicates that it takes a lot more time and effort to pick orders for these routes, and there is no measure of how this impacts productivity.
- Analysis of variance of productivity between shifts: A one-way ANOVA hypothesis testing was performed to compare differences in productivity between shifts, with a null hypothesis of both being the same, using a 5% significance (α) level (by definition, α level is the probability of rejecting the null hypothesis when it is true). It is revealed that there is a statistically significant difference in productivity between at least two groups, where the productivity of T2 is higher, so H_0 was rejected. This is because products are entering the warehouse during the day shift, so stacker cranes are not moving exclusively for order picking, and there are more full pallet picks during this shift.

- Correlation analysis of variables with productivity:
 - Shift 1: Total picks (0.23); Average order line (-0.18).
 - Shift 2: Total picks (0.40); Average order line (0.19).
 - Examining each group of route's influence on productivity by comparing the daily % of each route's picks on the total picks, the ones that have more than 0.5 negative influence constitute in total less of 1.5% of total picks of the whole database, so this influence is difficult to measure. A similar study of the effects of the average order line per route didn't result in any relevant effect on productivity.
- Descriptive analysis:
 - Picks of the pallet warehouse corresponds to 84% of the total, with the remaining being on the miniload warehouse;
 - Average order lines between shifts and picking posts are balanced, so the work among the operators is balanced;
 - Surprisingly, the workers with the highest percentage of total picks on both shifts are the ones who generally correct the most errors. From a performance measurement and gamification perspective, these are the most valuable workers (without considering picking errors) and deserve to be recognized;

Performing these studies with a more extensive historical data size would likely lead to more conclusive findings. However, this data allows for interesting observations and further comprehension of the current state.

3.7 Challenges to be Solved

The automated warehouse is the core of the distribution center's operation. A well-designed workflow of products has been established in this sector, with a visual and efficient picking method by a pick-to-light system that minimises errors and maximises efficiency and productivity, but a reduction of picking errors remains a valuable concern for the company to provide an even higher quality service level.

Despite this, the picking process is tiring due to its repetitive nature, and the regular necessity to correct machine breakdowns while having to keep up with productivity standards. It's no surprise that this sector is viewed by the majority of workers of all sectors as the most challenging, compared to others, and has had the most turnover rate in the last years. Other challenges are related with:

- Maintenance: The more regular corrective maintenance results from a low frequency and effectiveness of preventive maintenance interventions, which in turn happens because there's a lack in information regarding the machine stops.

Attempts to record the errors have been met with great resistance due to the need for workers' intervention. Given the dimension of the operation and its reliance on the AW, these

measurements would be highly beneficial, so the challenge to be solved is that a record has to be quick, effective, accurately calculate the duration and simultaneously retrieve all the necessary information.

- KPIs:

- Maintenance KPIs of the AW aren't measured;
- The visualisation and type of KPIs analysed depend on the levels and functions of the company:
 - * At the operational level, paper recording serves its purpose. Still, a more visual comparison for all operators of the work done in this sector would lead to higher engagement with the operation;
 - * A weekly kaizen meeting is held where indicators of all sectors of the SC are shown and displayed on a board, in a similar way as the daily kaizen. Finally, monthly indicator reports are done and exhibited at meetings every four weeks;
 - * At the highest management levels, there is no accessible view of the current status of the KPIs in a dashboard format, only by the daily productivity log files.
- No consideration of the complexity of picks and its impact on productivity (orders lines with more quantities per pick);
- The productivity measurement by the number of picks made doesn't value the workers that have to invest their time correcting the machine stops, since an operator that is not able to fix the issues will, in theory, do more picks at the end of the day than the ones who correct the errors. The supervisors are obviously aware of the workers who most often fix errors, and this skill and experience are valued, but comparing the worker's total picks with the actual number of errors and time invested in correction would allow for more accurate performance measurement.

The extensive review and comprehension of the various elements and issues of the picking process allow the work in this area to be characterised as complex and demanding, with low-engaged personnel, even though it is an extremely valuable operation. Knowing the general benefits that gamification applications have if correctly applied, it seems evident that, with the current state of the picking operation, there is a high potential to make a long-lasting impact, from the way performance is measured and shown to the overall engagement of the workers and the appeal of the picking operation.

Chapter 4

Development of Improvement Measures and Expected Results

Having examined the numerous aspects of the picking operation and major challenges to be addressed in this project, the development process for each main improvement measure to increase engagement and performance in this sector - Digitalization and visualization of KPIs in a dashboard; Application for error logging; Public display in the picking area of past and real-time updated metrics of this sector; Definition of game plans using existent metrics to promote competition and increase motivation - is detailed in this chapter.

Considerations and objectives of each are discussed, and new performance metrics are proposed. Furthermore, expected results and the next developments for all implementations are given, since they couldn't be carried through completely in the timeframe of the dissertation. Finally, an analysis of the most adequate way to adapt the game aspect of the app to CIN's operation is given as well as the game plan ideas that make the most sense for the near future.

4.1 Suggestions of New KPIs

Understanding the multitude of factors that influence productivity, additional performance indicators are proposed for more accurate performance measurement:

- Maintenance: Number of errors; Availability Rate; MTBF; MTTR; MTTF.
- Impact on Productivity: Average order line (quantities per pick); Types of orders being fulfilled (routes); Error correction time spent.

The viability of using other indicators commonly used in these operations was considered as well, but they were dismissed due to various reasons:

- Impact on Productivity: Average weight/volume of the order line. Average quantity per pick is perceived as a better estimator of effort since it's easier to get data on the number of items and there are manual tools that help workers carry the bigger or heavier loads;

- Time/Velocity per pick: Depends greatly on the quantities per pick, and being faster can lead to picking errors.

4.2 Partnership with Gamification App

The project methodology and the improvement proposals were co-developed with an external start-up company, Vaibe, that provides a gamification app. This partnership constitutes an ongoing pilot project in this sector in Portugal, where product features are being developed and closely tailored to CIN's operation and requirements. Their gamification approach functions through the use of the company's key performance indicators for employees' performance measurement.

4.2.1 Manager App Features

In the Manager app the following functionalities are present (Figure 4.1):

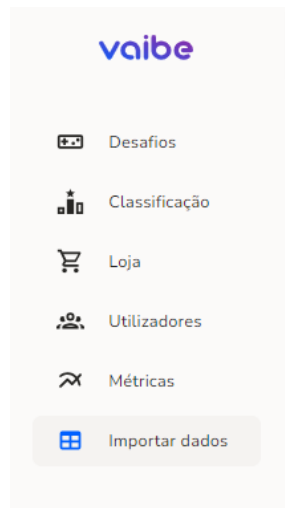


Figure 4.1: Manager app functionalities (displayed in Portuguese)

- Create game challenges associated with work-related metrics for users to play and gain rewards;
- Access user leaderboard of engagement tracking with the app;
- Monitor key performance metrics via dashboard;
- Customize store (add new avatars or background photos for user profiles);
- Define and manage users;
- Import metrics data, either through Excel files or real-time data input via API integration with the Warehouse Management System.

4.2.2 Worker App Features

A template (not related to this operation) is provided in Figure D.1 of Appendix D. In this app, the workers will be able to:

- Access their performances in previous challenges;
- See their leaderboard position range and how close he is to reaching the next place and the top 3 performers;
- Get summary feedback on the work done that day, and compared to his average;
- Customize their avatars and app through coins earned by completing challenges, creating a personalized identity within the app.

4.3 Digitalization of KPIs - Manager Dashboard

The first improvement measure corresponded to the digitalization and adaption of the company's KPIs and data inputs to the Manager app, to show information in a dashboard. Pick Rates for both shift and total for the warehouse, and Total Picks where the distinct components (classified as Normal Picks, Miniload Picks and Full Pallets Picks) of this metric were uploaded (Figure D.4 of Appendix D) and are displayed on a graphic (Figure 4.2). In addition, data from an error logging app (detailed in Section 4.4) will also be displayed.

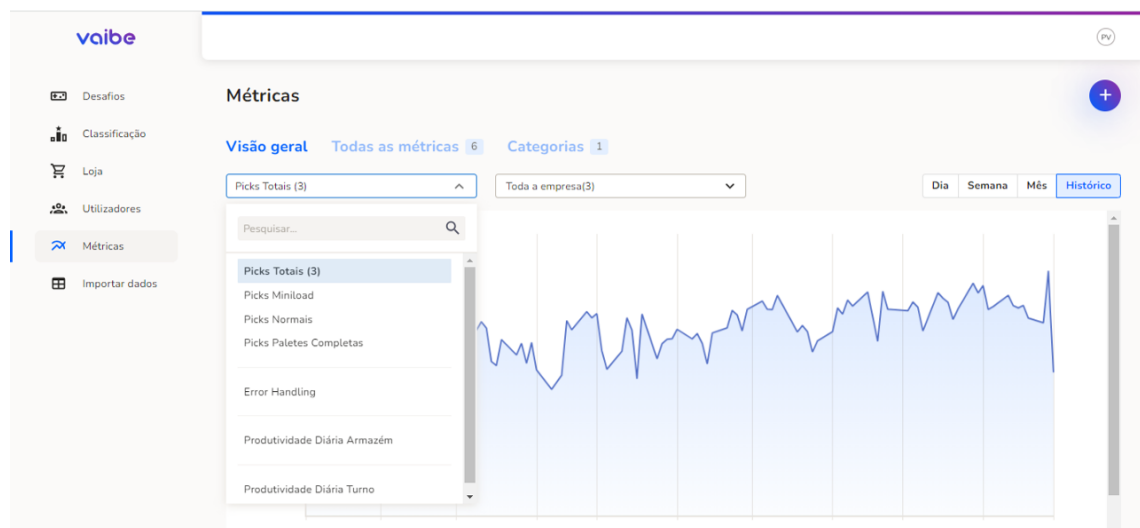


Figure 4.2: Current dashboard status (displayed in Portuguese)

Regarding Vaibe's metric definition in the app, the following details are needed:

- Transaction ID: Unique reference;
- Name of the metric;
- Category (e.g. Miniload and Full Pallet Picks belong to the Total Picks category);
- Description of the metric.

User IDs were created for the different Shifts and the Automated Warehouse to refer to this metric. In the near future, the shifts be will be classified as teams instead of users, but due to this feature not being developed on time, this assumption was made to be able to exhibit data as soon as possible.

4.3.1 Data Import Transformation Process

With this in mind, the data from CIN had to be adapted to the app's format, and for this, Excel macros were developed for the different files where the indicators of CIN are stored. Every macro allows to input the data range the user wants data from, and for every metric, the respective macro inputs, outputs and different processes are shown in Figures 4.3, 4.4 and 4.5.

- Pick Rate per Shift: There is a distinct file for each shift (with similar but not exact formats) where the supervisor at the end of the shift inputs the total picks and total hours of work of each employee, calculating the pick rate this way; The respective output files generated for both shifts consists of the Shift Productivity metric's ID and Name, with the userID being related to the shift, followed by the corresponding value and date.

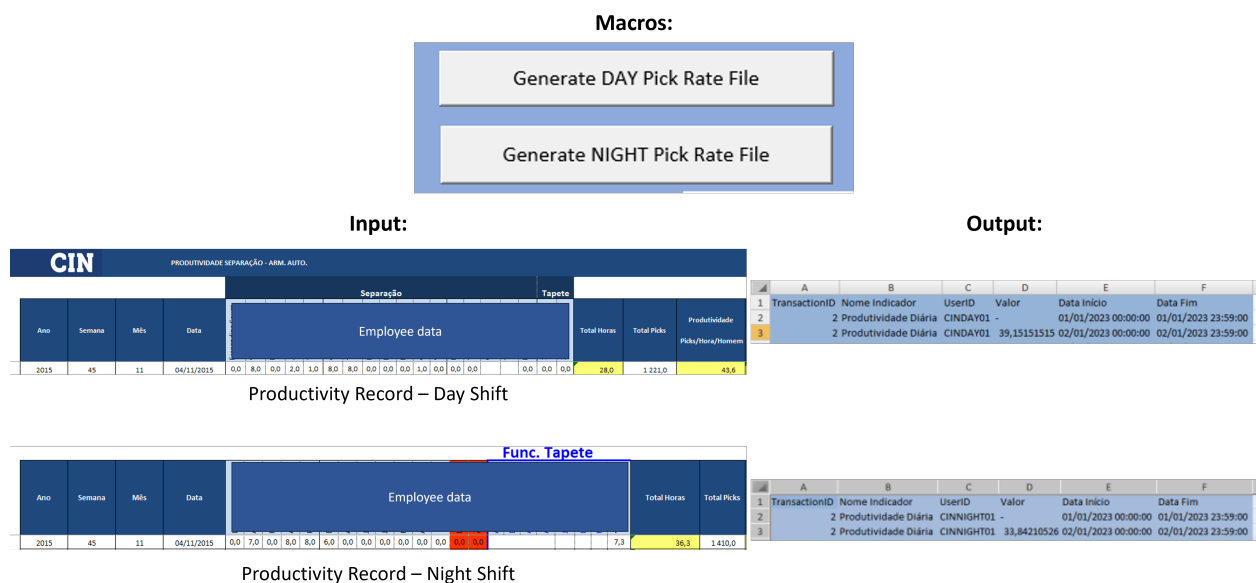


Figure 4.3: Data transformation process of day and night pick rate

- Total Pick Rate: This metric is calculated using pivot tables of both pick rates per shift files and dividing the sum of total picks of both shifts by the total hours worked. Like the previous pick rate file, the output categorises each line as the Total Productivity metric's ID and Name, with the userID being related to the Total Warehouse, followed by the metric's value and day.

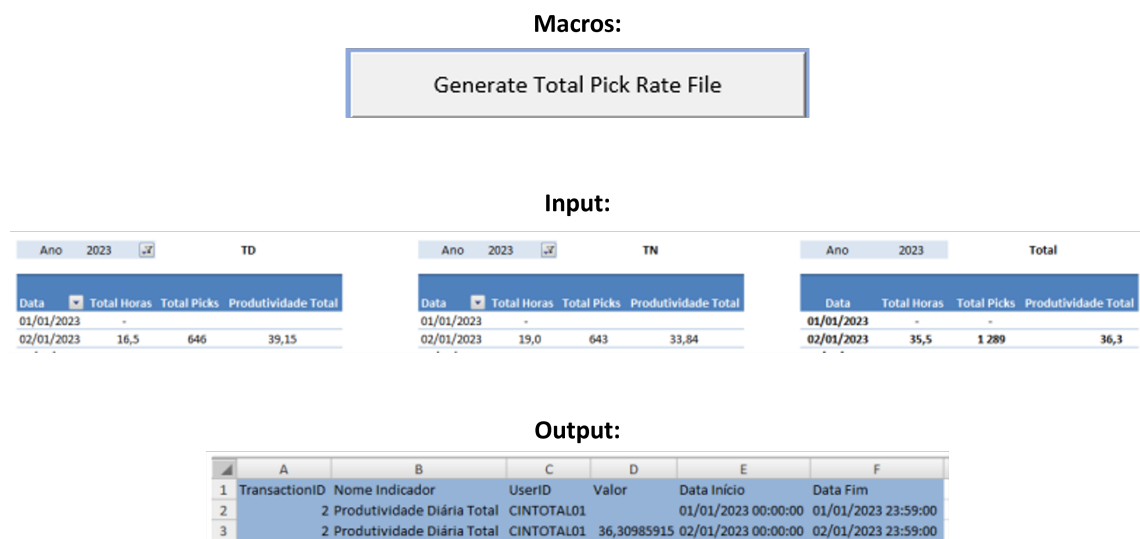


Figure 4.4: Data transformation process of total pick rate

- Total Picks and Categories: Two different data files can provide this information - Detailed Lines of Picks and Summary Picks.

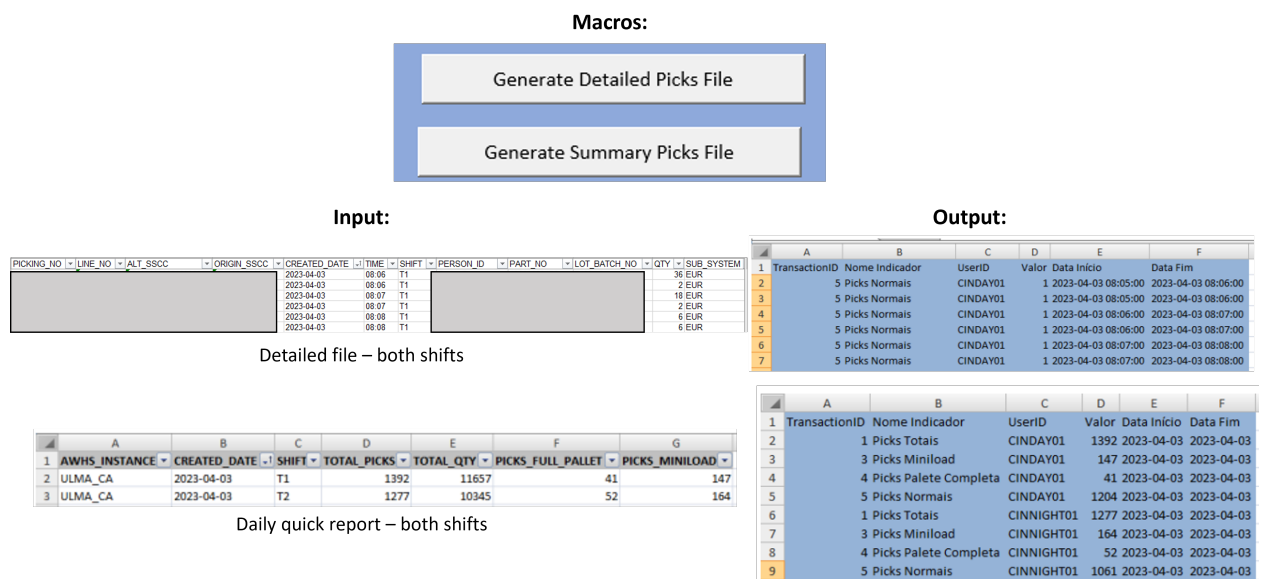


Figure 4.5: Data transformation process of total picks and components

- The first file has detailed information about every time a pick is done in the warehouse, such as the respective worker, the product that was picked, quantities, subsystem (miniloader or pallet warehouse), the type of movement (full pallet, reverse pick or normal pick), date and time, and the picking post. With all of this information, for every line, the macro classifies if it was a full pallet, miniloader pick or a normal pick of the pallet warehouse;

- The second is a file that can be generated at any time to display the current status of the warehouse key performance metrics regarding total picks and main components (miniload and full pallet picks); It is usually done so at the end of the day for a quick summary of the work done on the day. The output file generated presents on each line the value of a metric and the corresponding shift and other details;
- Both inputs allow uploading data of different metrics from the same file, although the data transformation from the Detail Picks file takes considerably more time to run. However, this file will still be important in the future to have data to measure each individual's picking performance.

4.3.2 Expected Results and Next Steps

This implementation is aimed at answering the challenge of not having an accessible dashboard for managers of the status of the warehouse for any specific period (Section 3.7 Challenges to be Solved). Data has been uploaded to the app, though the dashboard's design is not yet final. Further developments being made are the ability to visualise the metrics with a graphs bar compared with the line reference of the respective metric's goals for a customised period, which would allow for a great comprehension of fluctuations from goals throughout time.

4.4 Machine Breakdown Tracking App

A practical solution for the error tracking problem is believed to have been achieved through a well-designed application of error tracking on tablets positioned in the picking posts. Considerations from multiple stakeholders (the Maintenance department, the supervisors, and most importantly, the workers who would perform these logs) were considered in this design process, through usability/proof of concept tests of the application with the operators and supervisors on the work floor.

To be expected, the Maintenance department wanted every piece of information possible, but to avoid a repeat of the past and have this record discontinued, a focus on the most straightforward approach possible was required. However, a suggestion of theirs was still taken into account for better maintenance intervention planning in the future (the movement of the machine when depth errors happen).

The final version of the app's design (to be shown in Portuguese) is displayed in Figure E.1 of Appendix E. In summary, the essential facts to register were:

- The user, using a QR code placed on the employee cards they have to carry with them (with the workaround possibility of identification with a PIN);
- The time spent correcting through a timer that will begin after the user passes the QR code;
- Origin, Type of Error and respective Cause;
- Confirmation screen with the possibility to return to any previous screen if the wrong option was chosen;

- In the end, he can correct another error if it is happening or if it returns to the initial screen automatically.

The register will follow a simplified flux presented in Figure 4.6:

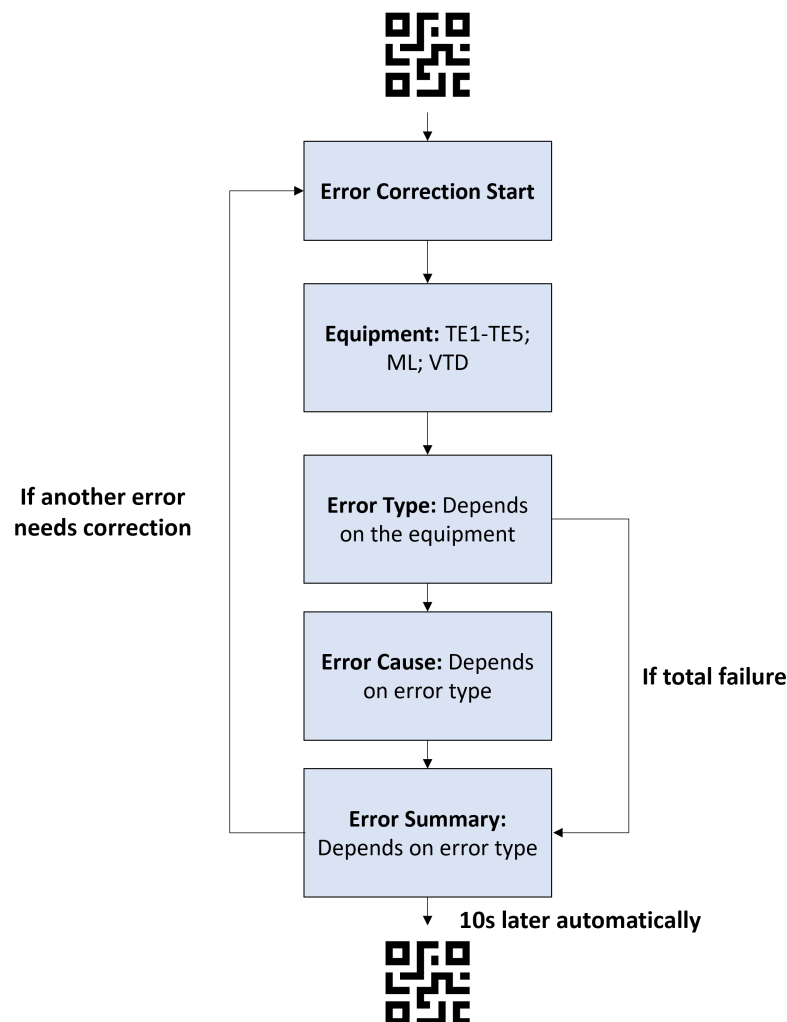


Figure 4.6: Error logging simplified workflow (Personal elaboration)

Having studied the causes (presented in 3.5.2.1 Types of Errors) of the most common errors, some error screens can be eliminated to make registration even faster, so for each:

- Depth: Eliminate Causes screen (always the same: pallet not centered correctly) and add a screen with details on the type of movement of the pallet (either loading or unloading a pallet). As mentioned, the Maintenance department suggested this, because if an error happens more frequently in one type of movement, they would know the specific part of the machine where to apply preventive maintenance.
- Load profile: Eliminate Causes screen (always the same: Loads with units exceeding the limit of the pallet).

- Beam not detected: Eliminate Causes screen (difficult visibility from the ground on what caused the error);
- Forks hitting the pallet: Include Causes Screen with options: Pallet slightly tilted; Pallet with damaged piece of wood sticking out;
- Positioning: Eliminate Causes screen (always the same: VTD laser doesn't align correctly with the pallet);
- Machine failure: It can occur on every piece of equipment, so it will appear in every Error Type screen. In this case, the workflow is a bit different due to the need of calling for an intervention and Figure E.2 in Appendix E reminds the worker to warn of this occurrence.

4.4.1 Other Considerations

- Eliminating the causes screen of the most common errors, Depth and Load Profile (Figure B.5 on Appendix B)) will lead to an even faster record;
- Stops due to a problem in the conveyors won't be registered since the operator usually has to move as soon as possible to fix these errors and so it's counterintuitive to have to stop and identify these errors;
- Having a limit timer in place in case the worker forgets to stop and record the error information (e.g. 10 minutes);
- The placement of the devices: If it was near the entrance of each stacker crane, the screen of the equipment registry would be eliminated from the flow, and the workflow would be simplified, but there is no near power plug and here is more difficult to position. In this case, the best solution is for it to be placed on every picking post (Figure 4.7), due to having a power plug available and also to be immediately next to the reader that identifies the machine errors.

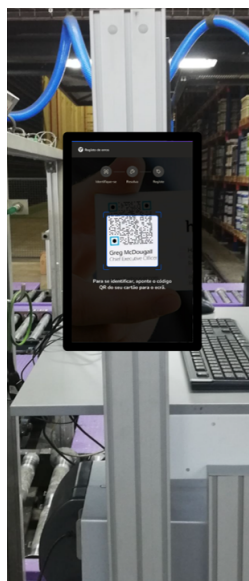


Figure 4.7: Proposed location of devices for error logging purpose

4.4.2 Expected Results and Next Steps

As mentioned, the reasons for implementing this solution are considered worth the time trade-offs of registering: provide the Maintenance department with a good estimator for better maintenance intervention planning, more accurately assess productivity and recognize the worker's time investment in this procedure. It is expected that gamifying this task will help reduce the workers' reaction time and resistance to go fix the errors knowing that they would finally be measured for this.

The data obtained is considered a metric and is available on the Manager App. In addition, an editable template for editing the information according to CIN's needs (if it is decided to measure other errors or change the flux of the app) will be provided. Continuous monitoring of the data obtained together with the Maintenance department is needed to perpetuate the calculation of maintenance indicators, as well as obtaining ongoing feedback from the workers and supervisors (the destined users of the app) of the impact of the time spent recording and the usefulness of it.

4.5 Public Displays in the Picking Area

This implementation was considered to be the main priority of the project, given the short time-frame and the existing app functionalities. The goal is to lead to a larger engagement and display the real-time status, progress of the work done in this sector and compare with previous days.

4.5.1 Design and Information Considerations

With the objectives defined, the crucial data to be displayed were discussed and resulted in the following:

- Displaying Total Picks (and components) information of the respective shift of the five previous workdays;
- Daily challenge of Total Picks considering the 39 picks per hour ($39 * 4 * 8$) with a progress bar filling up continuously;
- Graph bars with the Total Productivity (of both shifts) of the last five workdays;
- Compare the Total Productivity Rate of the day before with the prior five workdays;
- Finally, having information on news and weather would be a fun addition to the dashboard. Internal company-wide information could also be exhibited here.

Figure 4.8 illustrates the final design template with random data. The left part of the screen depicts the respective's shift information and the right side displays data concerning the total operation done for both shifts.



Figure 4.8: Final design template (to be displayed in Portuguese)

Other deliberations done were:

- Instant picking rate is hard to measure since its formula is based on the total picks and the total hours and is done at the end of each shift, so it wasn't viable to illustrate;
- At the switch between shifts (17h), change the screens to display information about the respective shift;
- The monitor has to be wide enough to be able to be viewed at a distance and has to be located at key points. Given the space constraints, the most viable solution evaluated is to place the monitor at the transition between the pallet and miniload system picking posts. Furthermore, since access to the picking posts can also be done near the exit conveyor and there's a worker assigned to pick up the pallets here, displaying information at this location is also deemed important. Figure 4.9 depicts these ideas:

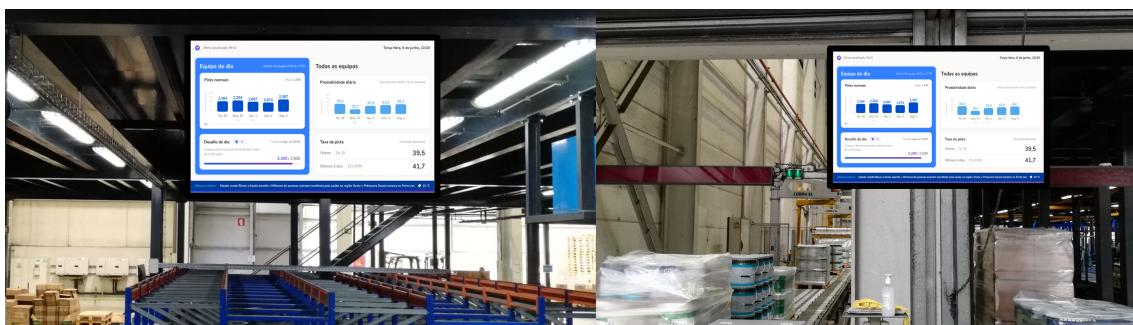


Figure 4.9: Proposed locations of public displays (Left - Picking area bottom floor; Right - Exit conveyor)

4.5.2 Expected Results and Next Steps

With the current data upload method using Excel files, the progress of the work will be uploaded hourly, using the quick summary files that can display the day's picks metrics throughout the day. Communication with CIN's IT department is being done to include Vaibe's already existing API integration with the WMS to update the data continuously throughout the day and not require manual input every hour. This would be the most effective solution, eliminating the need for the Summary and Detailed file inputs.

From a gamification perspective, different components of engagement, feedback, recognition and goal-setting visualization are evident: Having a daily challenge and visual performance progress updated in real-time and compared with the shift's work of the previous days, is expected to be very compelling to motivate workers (e.g. if they are tired almost at the end of the day but are close to the daily goal).

Future developments to be made are:

- Adding a reference line with each metric's goal;
- Displaying data obtained from the error logging app (errors and time spent, worker who has corrected the most errors that week) for awareness and recognition, and internal errors of the previous month with the respective goal, for the workers to be continuously aware of the need to reduce these errors;
- The worker at the top floor might feel disengaged due to not having a public display above or need a tablet (since stacker crane errors are only corrected on the ground floor), so a similar view of the public display on the tablet is being worked on, to display this information as a default screen and would give the operators information at every picking post;
- Finally, placing additional monitors on other strategic points of the warehouses (e.g. near the expedition area) for workers from other sectors to see will be an effective tool for engagement with this part of the operation.

4.6 Game Plan Suggestions

Due to the focus on the ideas presented so far and the worker app not being ready to be launched, only considerations regarding this and the game plans were made. Though to have a further understanding of how this part of the project and the app will function, an overview of the intended gamification system of the app is detailed next, followed by considerations on how to adapt to the environment and then, the final proposal for the first game plans.

4.6.1 Vaibe's Gamification System

The worker app will follow a Seasons concept, i.e. renovate the app every three months: Use new rewards, types of games, new avatars and backgrounds. The idea is to keep things fresh and to stimulate the worker to interact with the app.

The challenges can be either with a focus on Precision, Speed or Quantity, with a goal-based approach and can have various types: Player vs. Player; Cooperation; Team vs Team; Beat your best (Encourage to do more). Furthermore, with the Seasons concept, these challenges will be changed to renew the application as mentioned and appeal to all players with more competitive individualistic personalities or preferences. The challenge creation process is shown in Figures D.5, D.6, D.7 and D.8 of Appendix D and the performance of the app will be measured with the criteria shown in Table D.1 of Appendix D.

Further ideas are to have a feedback system in place for users to give their opinion on the type of rewards and challenges (if they are working well and users like them or not). This is in line with the literature as a continuous need to assess user preferences and adapt to individuals is essential for this app and type of gamification to result.

Showing a daily summary of the work done for each user and how it compares to their average will also be an important feature, due to the recognition aspect and to feel a sense of progress throughout time.

Concerning the leaderboard view:

- Worker View: It's deemed necessary that the worker doesn't see everyone's absolute value about who is on top and only the range where he is located and how close he is to reach the next place. This is not to demotivate workers.
- Manager View: The leaderboard view of the manager (shown in Figure D.2 of Appendix D) only shows participation points of users.

4.6.2 Adequate Adaptation to the Operation

To define an adequate game plan through co-developed findings and analysis of key factors from CIN's operation, the following reflections were done:

- Games should always be played as a team: Starting out with competition between individuals could lead to a toxic and competitive work environment which ultimately damages engagement and productivity instead of boosting it;
- Teams should be defined as Night and Day, representing both shifts: Seeing as this separation already exists and that only workers from each shift work with each other, it's intuitive and ideal to pair workers from both shifts into teams;
- Players must never see the score or target goals from the other team: Having statistical evidence that the productivity of T2 is higher (Section 3.6), the shifts have different productivity targets. It would be best for one team not to see the other team's target and data to avoid workplace conflicts.
- Daily Targets mean Daily Games: Performance measurement is already tracked based on a set daily target, and this process can easily be gamified, turning targets into challenges on the app;

- Other existing initiatives can be gamified: Absenteeism and improvement suggestions from workers are already traced and are easy to be gamified.
- No worker app during the shift time: The public display will allow for visualization of performance in real time. In the first implementation, only team-related metrics will be followed so the worker app won't be made available for the workers in this timeframe.

Eventually, when the app is established, access to the app to track individual performance while working won't be allowed because picking operations requires a lot of focus and would distract the employees. Nowadays, they are also instructed not to use their phone devices while working. Finally, if they want to access the app during break periods, it makes sense to block access to the metrics of that day and only refresh at the end of the shift, to provide individual daily performance stats at the end of the shift, providing instant feedback and recognition just after they exit work.

- No rewarding: Given the focus on teams, the user's app won't be introduced, so rewards won't be given for the daily performance. In addition, the complex nature of providing external rewards must be well considered with the HR department and the organization's practices.
- Games should focus above all on Precision or Quantity: Though challenges focused on Speed can be created, incentivizing speed when working can lead to picking errors, so this must be avoided.

Existent metrics with targeted goals or quantifiable/recurrent are the ones that make the most sense to be gamified first:

- Work related metrics: Picks and Pick Rate
 - These KPIs are already being tracked and have associated targets, so they are considered to be reliable indicators of success and already are, in a way, gamified. In the gamification process, these success indicators can be transformed into game-winning conditions: Reaching these goals means succeeding at the daily challenges;
 - Victories in the challenges can also be considered if a certain amount of the target is met. This would be more adequate for the operation due to the factors affecting the stacker cranes' throughput for picking purposes and the linear approach of 1250 total picks. If this goal isn't met, it might be because there is not enough demand or there are frequent machine issues, it's not due to a lack of capacity from the operators. Recognising reaching a significant portion of the target even when the linear goal is not met due to external factors would be the right thing to do.
- Maintenance related metrics: Error logging

- Without proper error tracking, solving what is causing the error becomes significantly harder; in this aspect, a solution for the error tracking problem was provided while also creating games that reward players for proper and consistent error tracking to incentivize them to catalogue errors correctly as they come.
- A concern might be raised here that players might try to “game the system” by logging false errors or taking longer to fix errors. This would lead to fewer rewards since people wouldn’t score in work-related metrics when errors are being logged and corrected. Considering also that games are to be played as a team, there is no benefit in keeping machinery purposefully stopped to stop other players from getting points.
- Improvement suggestions: The improvement suggestions already have a yearly feedback target of 3 per worker. The timescale to give feedback is large, and gamifying the process can incentivize workers to give more frequent and relevant feedback

4.6.3 Schedule of Game Plans

Considering key factors from CIN’s operations and the metrics that can be gamified, three types of game plans that differ on the period (daily, weekly, monthly) are intended to be implemented first. These challenges must be introduced gradually to not demand too much from the workers at the start. In an initial timeframe, only challenges related to teams will be made due to not having individual performance measurements ready yet. Consequently, these challenges will only be viewed on the public display.

1. **Daily challenge of Total Picks per team (shift):** Details on Table F.1 of Appendix F

- This is the most standard type of challenge. It mirrors CIN’s existing daily goal while also communicating real-time performance to the workers and seeing how well they are doing relative to the target the manager expects of them.
- Managers have the freedom to tweak the values in this challenge. If, for example, they wish to increase the target to test out the capacity of their team, they are free to do so. However, managers should be cautious that a constant and repetitive increase of the target, especially in a challenge without a reward, can have diminishing returns if not fully backfire if the target gets far beyond the baseline the players had at the start.
- It is also worth noting that this is a team-based challenge. Therefore when individual-related metrics are introduced, it is expected that some players might fail to meet the individual target and others might surpass it. Based on the picks data, this is expected, and players who overachieve tend to make up for the results of players who underachieve, making the team overall able to reach the target.

2. **Weekly challenge of Error Logging for All teams:** Details on Table F.2 of Appendix F

- This type of challenge is made to incentivize players to make use of the error logging feature and know the ID of the player due to the QR code identification, individual performance can be tracked.

- Classic-type games are games without a defined target where the goal of the game is to simply score as much as one can. This is fitting for this type of challenge since it's impossible to predict how many errors will occur in a week and how many each player is expected to solve individually. Keeping the target open makes it so that the player that was most committed to logging and solving errors is considered the winner by the end of the week.
- Parameters can be altered at will, such as:
 - Duration: To track the number of errors logged per day, simply make the challenge a daily challenge instead of a weekly one, and the same can be applied to a longer time scale.
 - Participants: To track the number of errors per shift, the participants can also be changed to include only players from a specific team in the challenge. Although, due to the limited number of people that can solve the breakdowns, a competition for all shifts makes sense from an engagement perspective, to involve every worker in this section, no matter the shift.

Finally challenges regarding Pick Rate (Productivity):

- Since this metric is not calculated on real-time, only at the end of each shift, it only makes sense, for now, to display this metric and not create a daily challenge to be shown in the public display, since it won't be updated on real-time like Total Picks;
- Due to statistical differences between the Pick Rate of both shifts, a competition-based game for reaching the same absolute productivity goal is not fair. For example, if the pick rate of T1 is around 40 and T2 is around 43 challenging them to reach a value of 44 will lead to biased results since the Night shift is more likely to reach it. Consequently, it is done, it has to be on a relative (%) basis (e.g. Challenge both teams to reach 5% more of their average pick rate);
- Besides this, competitions based around this metric might not reach substantial improvements due to the fact that it is affected by several factors as known already, like machine errors.

Example months - Initial, Average and Complex - with the challenges defined in this section are shown in Figures F.1, F.2 and F.3 of Appendix F.

Chapter 5

Conclusions

The present dissertation focused on the development process of an innovative pilot project of the implementation of a Gamification app to be applied in the order-picking operation of the automated warehouse to increase engagement of the workers and productivity, and provide a more accurate estimation since it is impacted by many factors.

5.1 Summary of the Work Developed and Expected Results

The project covered the development of four main implementations, after studying the operation's functioning, performance measurements and factors that negatively influenced the picking operation. Looking back at the initial objectives, even though results couldn't be obtained on time, with the thorough development of the different implementations, it can be said that this on-going project will revolutionize how this operation works for the better and have a long-lasting impact.

Regarding the public display, having instant progress and comparison of performance will likely lead to higher engagement and motivation of the workers, due to the clear goals and progress feedback features.

Gamifying an error logging task that had strong resistance to in the past might be just the change it needed for this record to persist, reduce the reaction time of fixing the errors, and change the way it is viewed as a valuable task for both Maintenance and measuring AW Productivity and compensating the workers that invest their time in this task.

In addition, real-time information on the status of the picking operation and equipment will also lead to a better and more accurate productivity measurement of the warehouse. By displaying all of these metrics on a dashboard, it will be easy to understand productivity fluctuations and the reasons for it.

With the factors that affect the throughput of the machines productivity gains from competition game plans measured on key performance indicators might not be substantial. Although most likely they will be valuable to remove the stigma of the picking work being boring and difficult and turn it into something fun.

5.2 Limitations

Regarding the picking operation, it was surprising to see the impact of the frequent machine breakdowns on the warehouse productivity and the workers' morale.

The use of Gamification in every sector has its intricacies, especially in this kind of sector where there have not been many real-life examples, and there are a lot of factors to consider. Given the existent HR policies, the component of physical rewards won't be initially present in the implementation of this app. This might be a limitation on the long-term influence of the app since motivation provided by the other gamification features or digital rewards will only go a certain way. This implementation has to be very carefully implemented though for the employees not to start prioritizing this instead of the work.

Another limitation was the difficulty in communicating with other departments, such as Maintenance, for better understanding and obtaining data on maintenance issues, and IT to integrate Vaibe's software with the company's WMS.

5.3 Future Work Perspective

For the implementation of games, a recommended plan of action is to first measure the impact of the public display and error logging features, then start introducing the app and rewards gradually. Closely monitoring the effect of this application on the workers and adapting correctly to their individual preferences and concerns is needed. In addition, the effect that this app can generate on workers from other sectors (they might be interested or jealous) has to be taken into account.

Coordinating with Maintenance department will be fundamental for this way of obtaining data to remain. Further work has to be done to calculate the indicators automatically and display them on the dashboard and public display.

A longer time study to understand the impact on productivity and justify implementing the Key Performance Indicators suggested will be necessary. Regarding Maintenance KPIs, Availability Rate and MTBF are considered to be the ones that better represent the status of the equipment. Finally, the digitalization of metrics should also be applied to every sector of the Distribution Center, for improvement of the whole operation.

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Appendix A

Automated Warehouse General Information

Table A.1: Stacker crane designations

Stacker Cranes	Corresponding Aisle
19	1
29	2
39	3
49	4
59	5

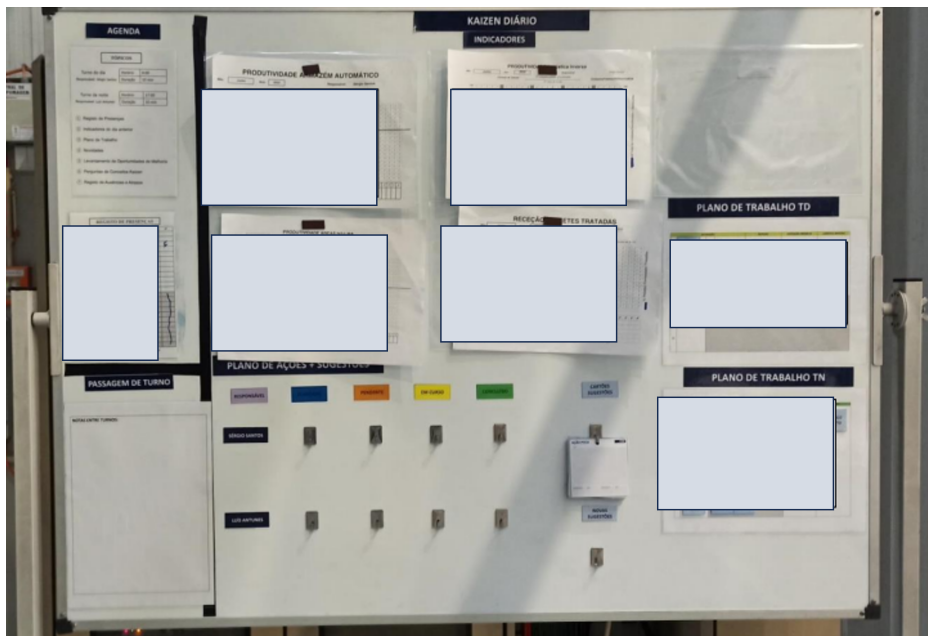


Figure A.1: Daily Kaizen board

Appendix B

Machine Breakdowns

Armazém Automático																													
Semana	Tempo - min	Ocorrência nos Transelevadores													Resets					VTDs		Avaria	Paragem programad	Nível do armazém	Turno	Observações			
		Transelevador					Horquilla			Perfil Carga					Viga não detectada	Outro	Zonas										Local		
										HP	L	E	P	S													E	P	S
		1	2	3	4	5	ML	HP	L	E	P						S	E	P	S	Geral								
41	3			X				X																				TD	
41	6	X								X																	TD	15 LT	
41	50			X																						X	TD		
41	65						X																			X	TD		
41	70			X																						X	TD		
41	25						X																			X	TD		
41	40				X																					X	TD		
41	60					X																				X	TD		
41	3			X					X																			TD	

Figure B.1: Example of the old template used to register breakdown data

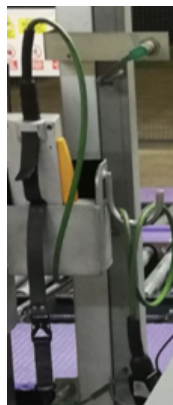


Figure B.2: Equipment used to read the breakdowns of the stacker cranes

										Ocorrência nos Transelevadores				
Período			Total horas/di	Err	Data	Turri	Deteçã	Início Correção	Fim	Tempo detecção à correção	Tempo correção	Tempo total	Origem Erro	Tipo de Erro
Início	Fim	Duração												
09:30	12:00	2:30:00	03:00:00	13	03/03/23	T1	9:40	9:40	9:45		0:05:00	0:05:00	TE5	Horquilha
					03/03/23	T1	9:48	9:48	9:50		0:02:00	0:02:00	ML	
					03/03/23	T1	10:05	10:05	10:08		0:03:00	0:03:00	Tapete parado	Paleta avançou mais do que o suposto
					03/03/23	T1	10:10	10:10	10:16		0:06:00	0:06:00	TE4	Horquilha
					03/03/23	T1	10:24	10:24	10:26		0:02:00	0:02:00	TE4	Horquilha
					03/03/23	T1	10:34	10:34	10:39		0:05:00	0:05:00	Tapete parado	Paleta avançou mais do que o suposto
					03/03/23	T1	10:39	10:41	10:45	0:02:00	0:04:00	0:06:00	TE3	Garfos a bater na carga
					03/03/23	T1	10:57	10:57	11:01		0:04:00	0:04:00	TE4	Horquilha
					03/03/23	T1	11:08	11:08	11:11		0:03:00	0:03:00	TE5	
					03/03/23	T1	11:36	11:36	11:40		0:04:00	0:04:00	TE4	Viga não detetada
					03/03/23	T1	11:41	11:41	11:42		0:01:00	0:01:00	ML	
					03/03/23	T1	11:44	11:44	11:46		0:02:00	0:02:00	TE5	Horquilha
					03/03/23	T1	11:46	11:46	11:48		0:02:00	0:02:00	TE4	Perfil carga
16:30	17:00	0:30:00		3	03/03/23	T1	16:31	16:31	16:39		0:08:00	0:08:00	TE5	Horquilha
					03/03/23	T1	16:40	16:40	16:43		0:03:00	0:03:00	TE4	Perfil carga
					03/03/23	T1	16:45	16:45	16:48		0:03:00	0:03:00	TE1	Perfil carga
					07/03/23	T1	9:52	9:54	9:55	0:02:00	0:01:00	0:03:00	TE3	Perfil carga
					07/03/23	T1	9:58	9:58	9:59		0:01:00	0:01:00	TE4	Horquilha
					07/03/23	T1	10:12	10:12	10:13		0:01:00	0:01:00	Tapete parado	Paleta torta no tapete
					07/03/23	T1	10:12	10:13	10:15	0:01:00	0:02:00	0:03:00	TE2	Perfil carga

Figure B.3: Manual error logging record data example (Personal elaboration)

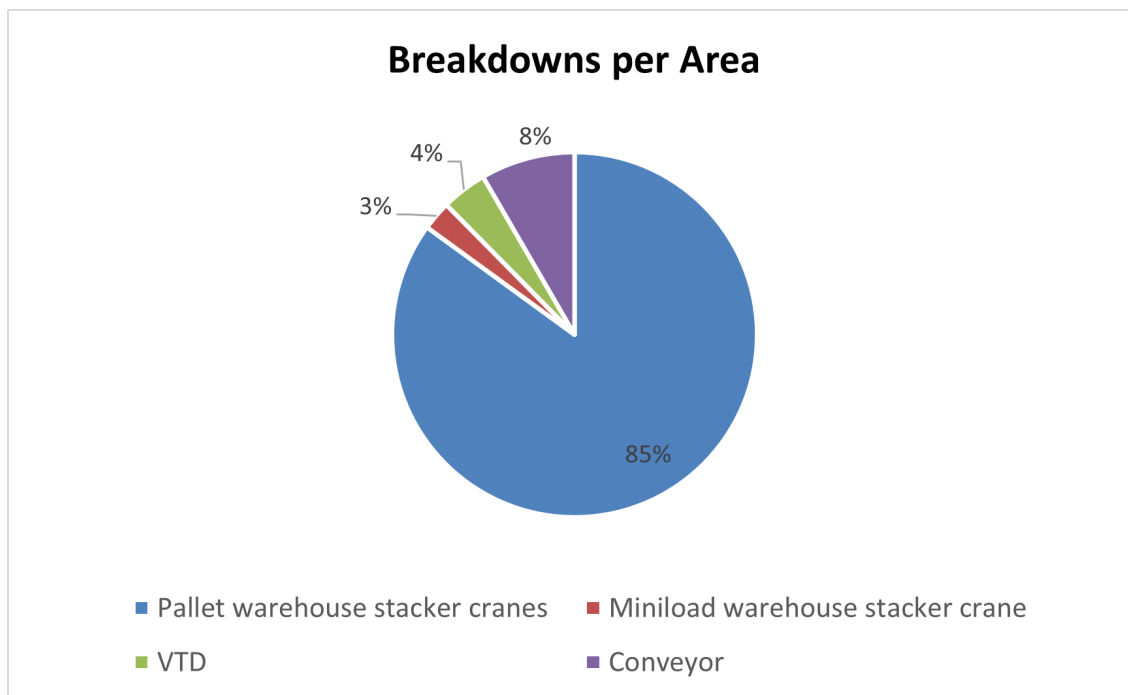


Figure B.4: Breakdowns per area

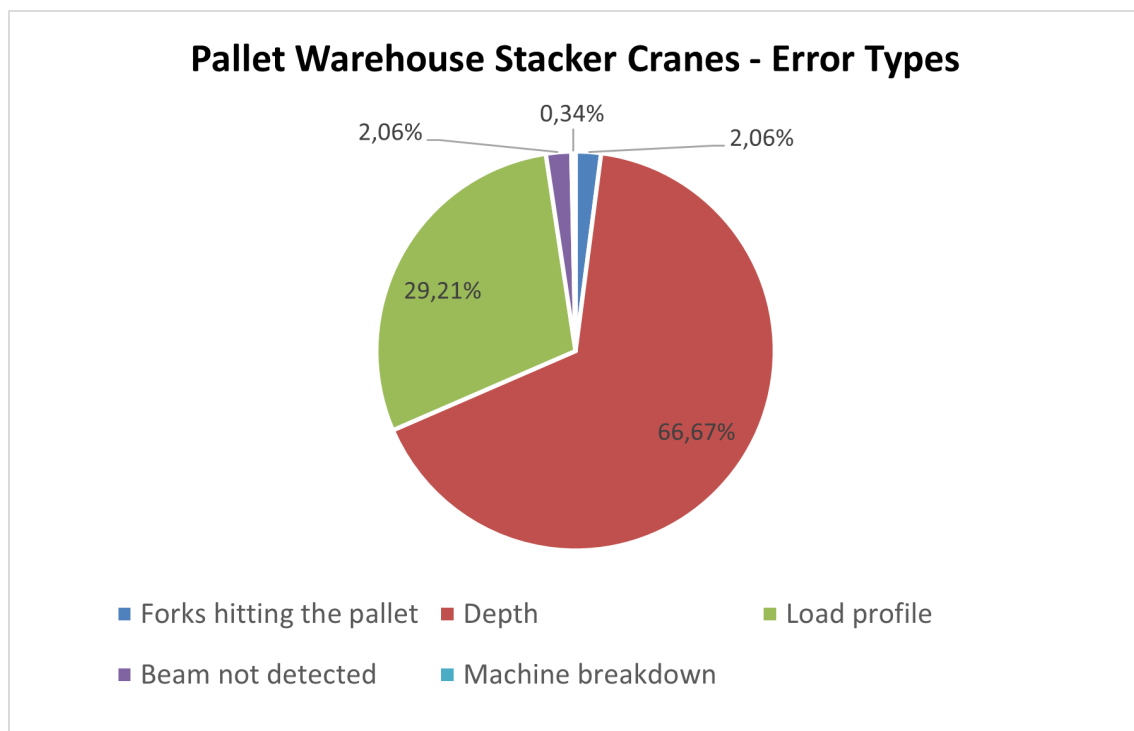


Figure B.5: Breakdowns per error type

Table B.1: General information of the sample analysis

Start date	03/03
End date	26/04
Number of days	31
Total analysis time	68:20:00
Conversion to total shifts	8.54
Average time spent per day	02:12:15
Total number of errors	347

Table B.2: Error times per equipment

	Average Correction Time	Average Total Stop Time
TE1	00:02:29	00:05:10
TE2	00:02:35	00:05:21
TE3	00:02:19	00:04:37
TE4	00:02:30	00:03:56
TE5	00:02:31	00:04:32
ML	00:05:00	00:08:27
VTD	00:02:34	00:02:39
Conveyor	00:05:46	00:06:50

Table B.3: Descriptive statistics of error times

	Error Reaction Time	Error Correction Time	Total Stop Time
Mean	00:01:43	00:02:49	00:04:33
Median	00:01:00	00:02:00	00:03:30
Mode	00:00:00	00:02:00	00:02:00
Std Dev	00:02:47	00:02:54	04:12:00
Range	00:17:00	00:34:00	00:45:00
Min	00:00:00	00:00:00	00:01:00
Max	00:17:00	00:34:00	00:46:00
Sum	09:57:00	16:17:30	26:20:30

Table B.4: Example of summary of data points of TE2

Data	Analysis Time	Downtime	Breakdowns
07/03/23	2:30:00	0:03:00	1
07/03/23	1:30:00	0:05:00	1
08/03/23	1:00:00	0:01:00	1
10/03/23	2:30:00	0:04:00	1
10/03/23	2:15:00	0:04:00	1
13/03/23	1:35:00	0:19:00	1
20/03/23	1:35:00	0:05:00	1
21/03/23	2:00:00	0:05:00	1
22/03/23	1:00:00	0:09:00	1
22/03/23	1:35:00	0:09:00	2
24/03/23	1:30:00	0:13:00	1
28/03/23	1:00:00	0:07:00	1
29/03/23	1:05:00	0:01:00	1
13/04/23	0:45:00	0:03:00	1
18/04/23	1:00:00	0:02:00	1
18/04/23	0:55:00	0:01:00	1
Total	23:45:00	1:31:00	17

Appendix C

Statistic Analysis Results

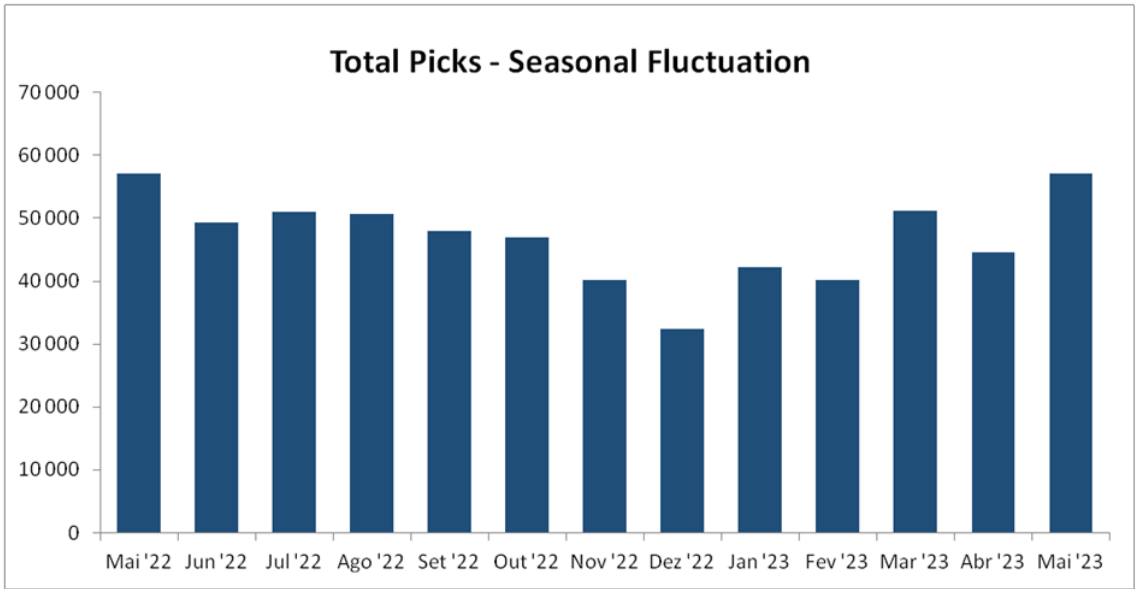


Figure C.1: Yearly Variance in Total Picks

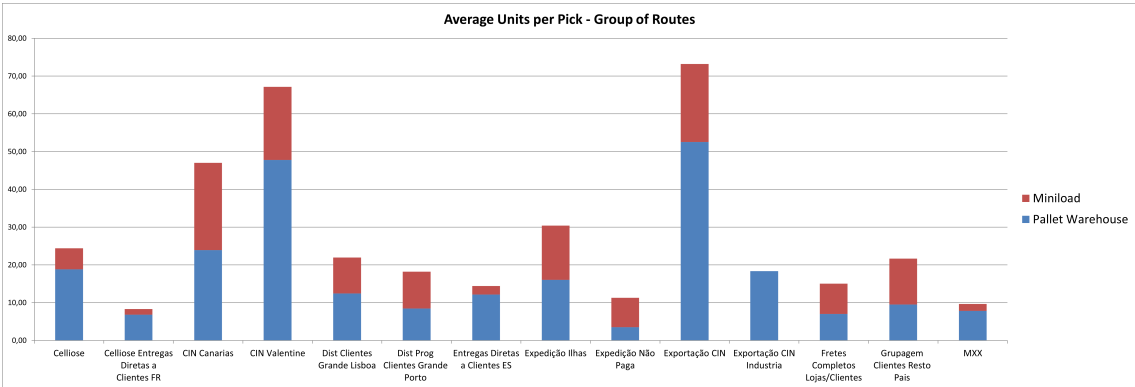


Figure C.2: Variance in average units per pick per group of routes

<i>Correlação T1</i>	<i>Horas Totais</i>	<i>Picks Totais</i>	<i>Quantidades Totais</i>	<i>Encomenda Média</i>	<i>Produtividade</i>
Horas Totais	1				
Picks Totais		1			
Quantidades Totais		0,55	1		
Encomenda Média	-0,15			1	
Produtividade	0,12	0,23	-0,04	-0,18	1

<i>Correlação T2</i>	<i>Horas Totais</i>	<i>Picks Totais</i>	<i>Quantidades Totais</i>	<i>Encomenda Média</i>	<i>Produtividade</i>
Horas Totais	1				
Picks Totais		1			
Quantidades Totais		0,66	1		
Encomenda Média	0,07			1	
Produtividade	0,14	0,40	0,39	0,19	1

Figure C.3: General correlation analysis

	Picks Totais T1	Picks Totais T2	Picks Paletes Completas T1	Picks Paletes Completas T2	Picks Miniload T1	Picks Miniload T2	Picks Armazém paletes T1	Picks Armazém paletes T2	Produtividade T1	Produtividade T2
Picks Totais T1	1									
Picks Totais T2		1								
Picks Paletes Completas T1			1							
Picks Paletes Completas T2				1						
Picks Miniload T1					1					
Picks Miniload T2						1				
Picks Armazém paletes T1							1			
Picks Armazém paletes T2								1		
Produtividade T1	0,23		-0,10		0,32		0,17		1	
Produtividade T2		0,40		0,20		0,35		0,29		1

Figure C.4: Type of picks correlation analysis

Anova: factor único - Produtividade entre turnos						
SUMÁRIO						
Grupos	Contagem	Soma	Média	Variância		
Produtividade T1	104	4084,297778	39,27209402	0,74613297		
Produtividade T2	104	4346,271917	41,79107612	4,16472586		
ANOVA						
Fonte de variação	SQ	gl	MQ	F	valor P	F crítico
Entre grupos	329,9540837	1	329,9540837	134,3773442	3,01668E-24	3,886996083
Dentro de grupos	505,8184595	206	2,455429415			
Total	835,7725432	207				

P-value < 0.05 (alfa) - H0 é rejeitada

F crit < F - H0 é rejeitada

Há diferença na Produtividade entre turnos (T2 > T1)

P-value < 0.05 (alfa) - H0 é rejeitada
F crit < F - H0 é rejeitada
Há diferença na Produtividade entre turnos (T2 > T1)

Figure C.5: Analysis of variance of productivity of both shifts

Rótulos de Linha	Picks (%)	Average Order Line	Average Order Line - Productivity Impact	% Daily Picks - Productivity Impact
Group of Routes 1	33,33%	7,17	-0,23	0,08
Group of Routes 2	24,53%	9,91	0,39	0,23
Group of Routes 3	20,98%	11,94	-0,16	-0,22
Group of Routes 4	8,91%	8,65	0,06	-0,25
Group of Routes 5	5,31%	15,72	0,17	0,04
Group of Routes 6	2,13%	41,29	-0,24	-0,01
Group of Routes 7	1,23%	12,13	0,00	0,00
Group of Routes 8	1,08%	18,37	0,05	-0,41
Group of Routes 9	0,94%	46,47	-0,20	-0,05
Group of Routes 10	0,79%	18,47	0,06	0,07
Group of Routes 11	0,53%	23,86	-0,15	0,21
Group of Routes 12	0,21%	7,30	-0,09	-0,53
Group of Routes 13	0,02%	6,55		
Group of Routes 14	0,01%	6,81	0,51	-0,59
Group of Routes 15	100,00%			

Figure C.6: Routes productivity impact analysis

Appendix D

Vaibe App Functionalities

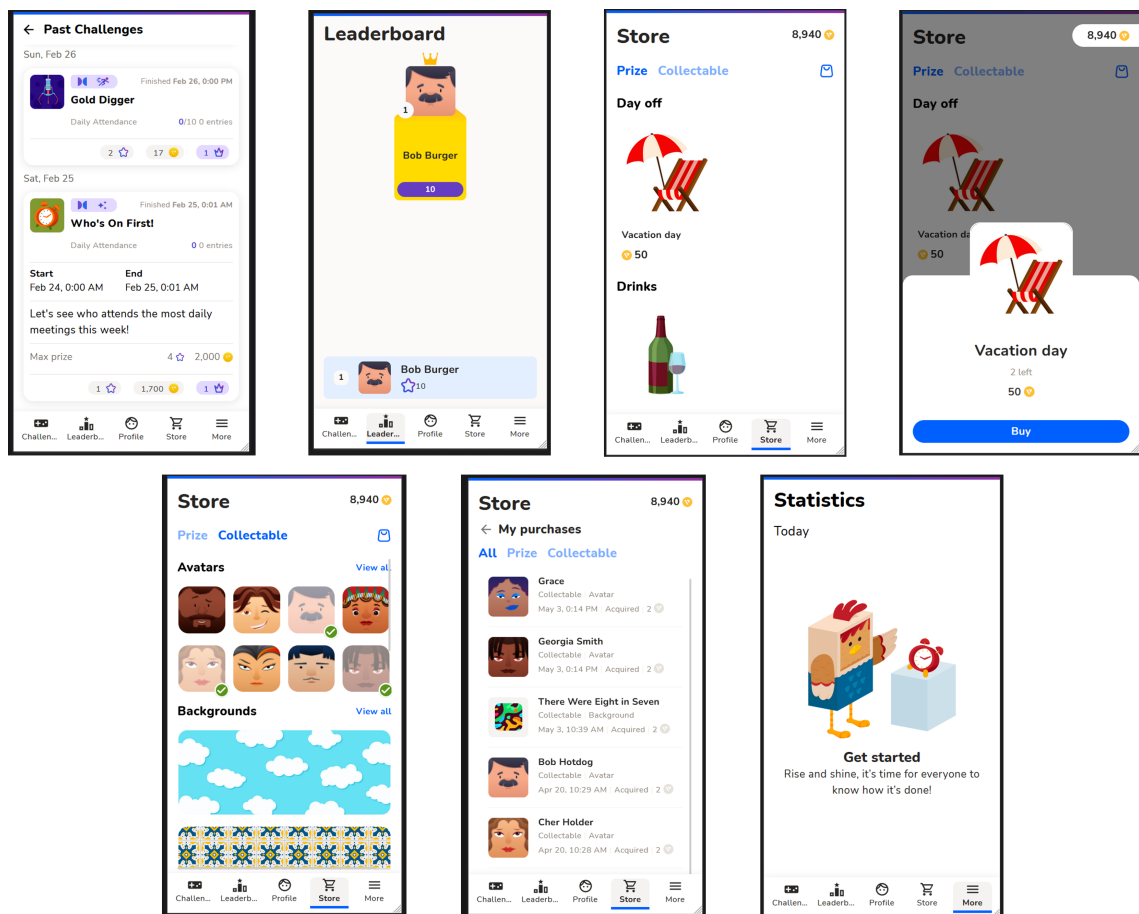


Figure D.1: Example of Worker app functionalities

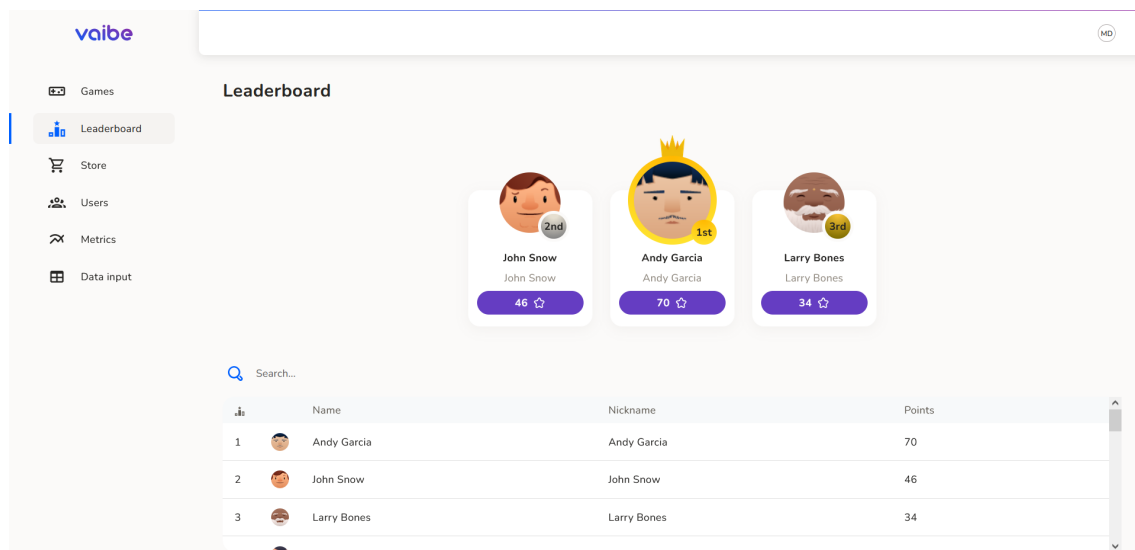


Figure D.2: Template of user leaderboard view in the Manager app

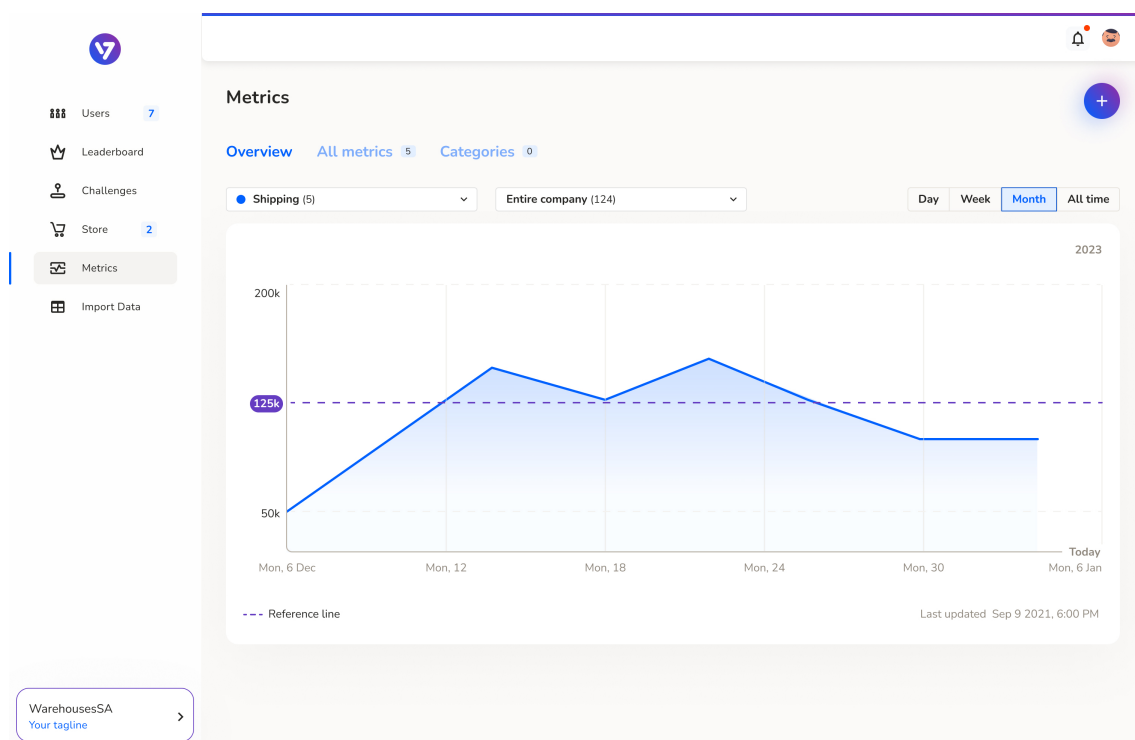


Figure D.3: Template of dashboard view with goal reference line in the Manager app

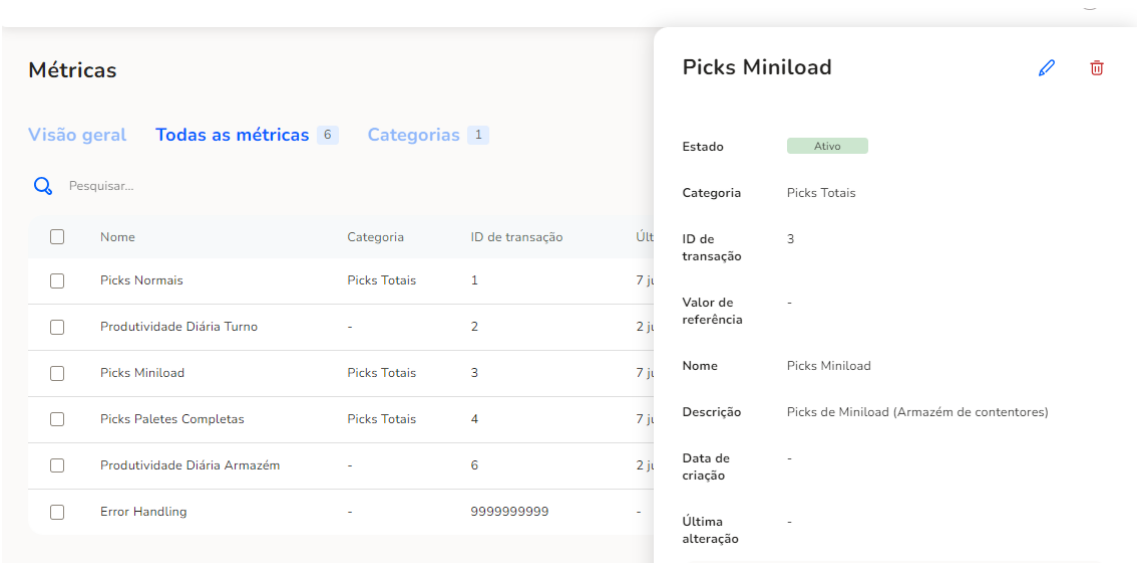


Figure D.4: Current uploaded metrics and format in the Manager app (displayed in Portuguese)

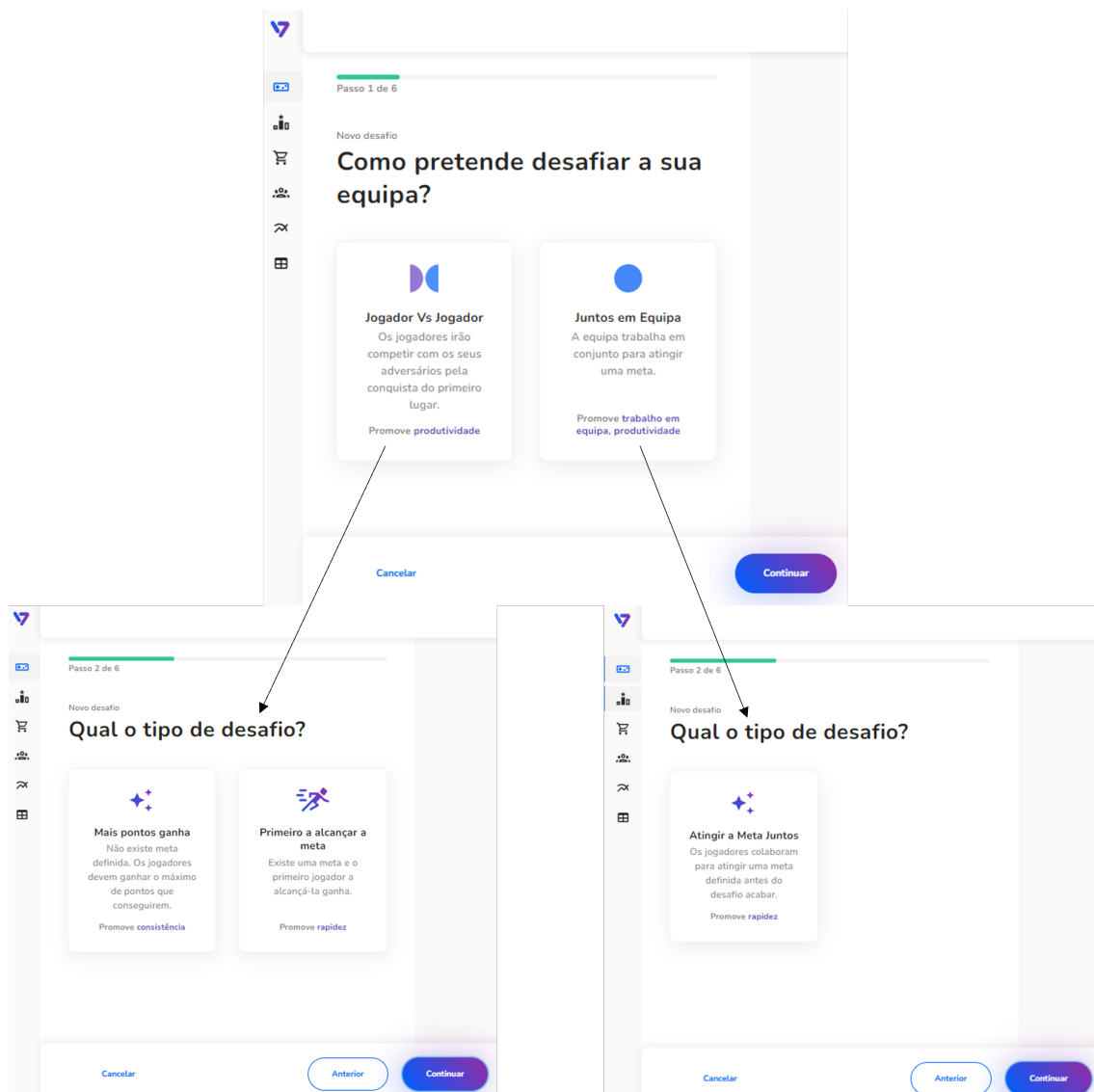


Figure D.5: Challenge types (displayed in Portuguese): Player vs. Player - Most points wins, first to reach wins; Team - Reach goal together

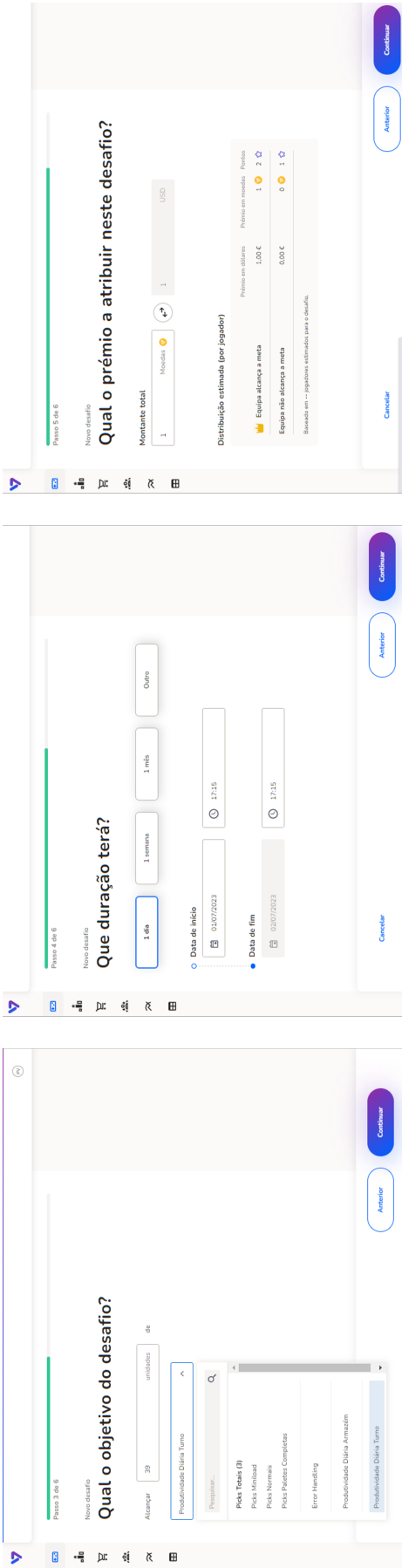


Figure D.6: Pick rate challenge creation details (displayed in Portuguese): Choose metric and goal, duration and reward

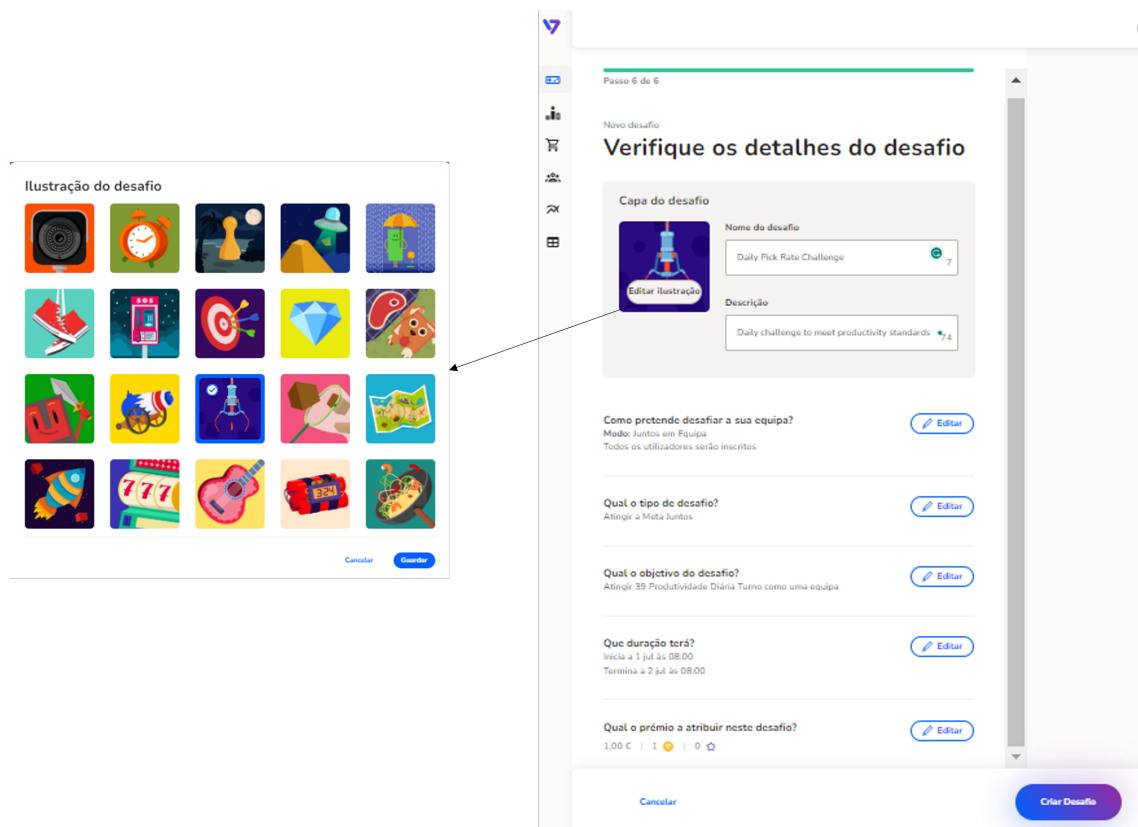


Figure D.7: Pick rate challenge creation summary (displayed in Portuguese): Review the details and attribute image to the challenge

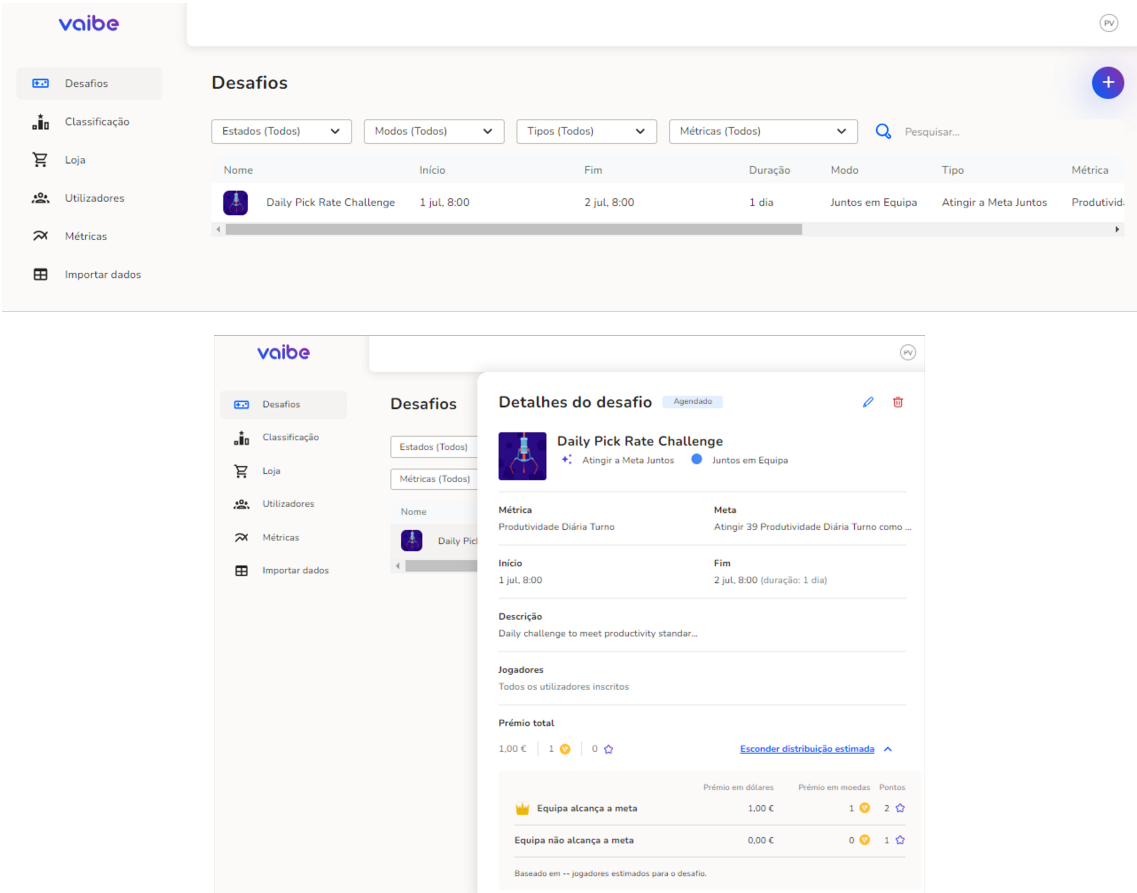


Figure D.8: Pick rate challenge creation finished (displayed in Portuguese): List and details

Table D.1: Measurement of user engagement with the app

User Engagement Metrics	
Gameplay Stats	Number of challenges played
	Number of challenge victories
	Number of top 3 placements
	Placement in all challenges for all workers
General Stats	% of users that login every day/week/month
	Time between logins
Store Stats	Number of digital items owned (avatars/background)
	Coins gained and spent per day
	Most expensive item acquired per account
	Most often purchased type of item
Most purchased item by all players	

Appendix E

Error Logging App Screens

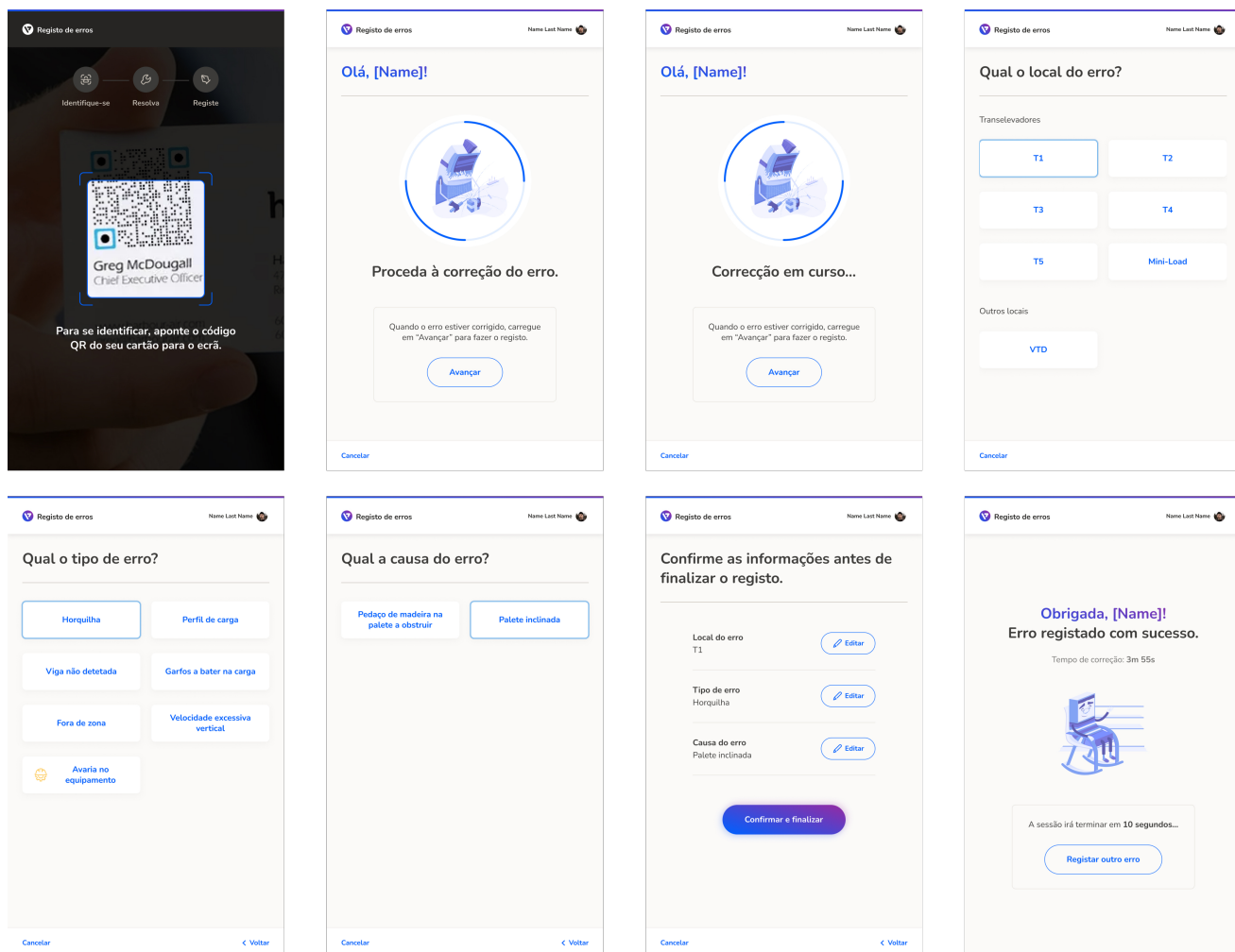


Figure E.1: Error logging normal sequence (final visuals, displayed in Portuguese)

The figure displays two sequential screens of an error logging application. Both screens have a header with a purple icon, the text 'Registo de erros', and a user profile placeholder 'Name Last Name'.

Left Screen: Qual o tipo de erro?

This screen presents a grid of error type buttons:

- Horquilha
- Perfil de carga
- Viga não detetada
- Garfos a bater na carga
- Fora de zona
- Velocidade excessiva vertical
- Avaria no equipamento (accompanied by a yellow warning icon)

At the bottom, there are two navigation options: 'Cancelar' and '< Voltar'.

Right Screen: Confirme as informações antes de finalizar o registo.

This screen is for confirming the error details. It includes:

- Local do erro:** T1, with an 'Editar' button.
- Tipo de erro:** Avaria do equipamento, with an 'Editar' button.
- Confirmation box:** Contains a blue information icon (i), the text 'Após confirmar, informe o responsável sobre a existência da avaria.', and a large blue 'Confirmar e finalizar' button.

At the bottom, there are two navigation options: 'Cancelar' and '< Voltar'.

Figure E.2: Error logging sequence in case of failure (displayed in Portuguese)

Appendix F

Proposed Game Plans

Table F.1: Details of total picks daily challenge

Daily Challenge: Total Picks per Shift	
Game Type	Reach a Target
Target	1250 picks = $39 * 4 * 8$
Win Condition	The team reaches the target in the allowed timeframe
Participant	All members of the team
Duration	8:00 – 17:00 (9 Hours) - Day; 17:00 - 02:00 (9 Hours) - Night
Rewards	Non-existent

Table F.2: Details of total picks weekly challenge

Weekly Challenge: Error Logging - All Teams	
Game Type	Classic
Target	Uncapped
Win Condition	The participant who logs the most errors
Participant	All individuals of all teams who are capable of solving errors
Duration	8:00 – 17:00 (9 Hours) - Day; 17:00 - 02:00 (9 Hours) - Night
Rewards	Non-existent

	CIN				vaibe
	Challenge Calendar				
	Initial Month				
Week 1	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks
	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks
Week 2	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks
	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks
Week 3	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks
	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks
Week 4	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks	Daily Day Shift Target 88 Picks
	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks	Daily Night Shift Target 88 Picks

Figure F.1: Game plan initial month proposal: Daily shift picks challenge

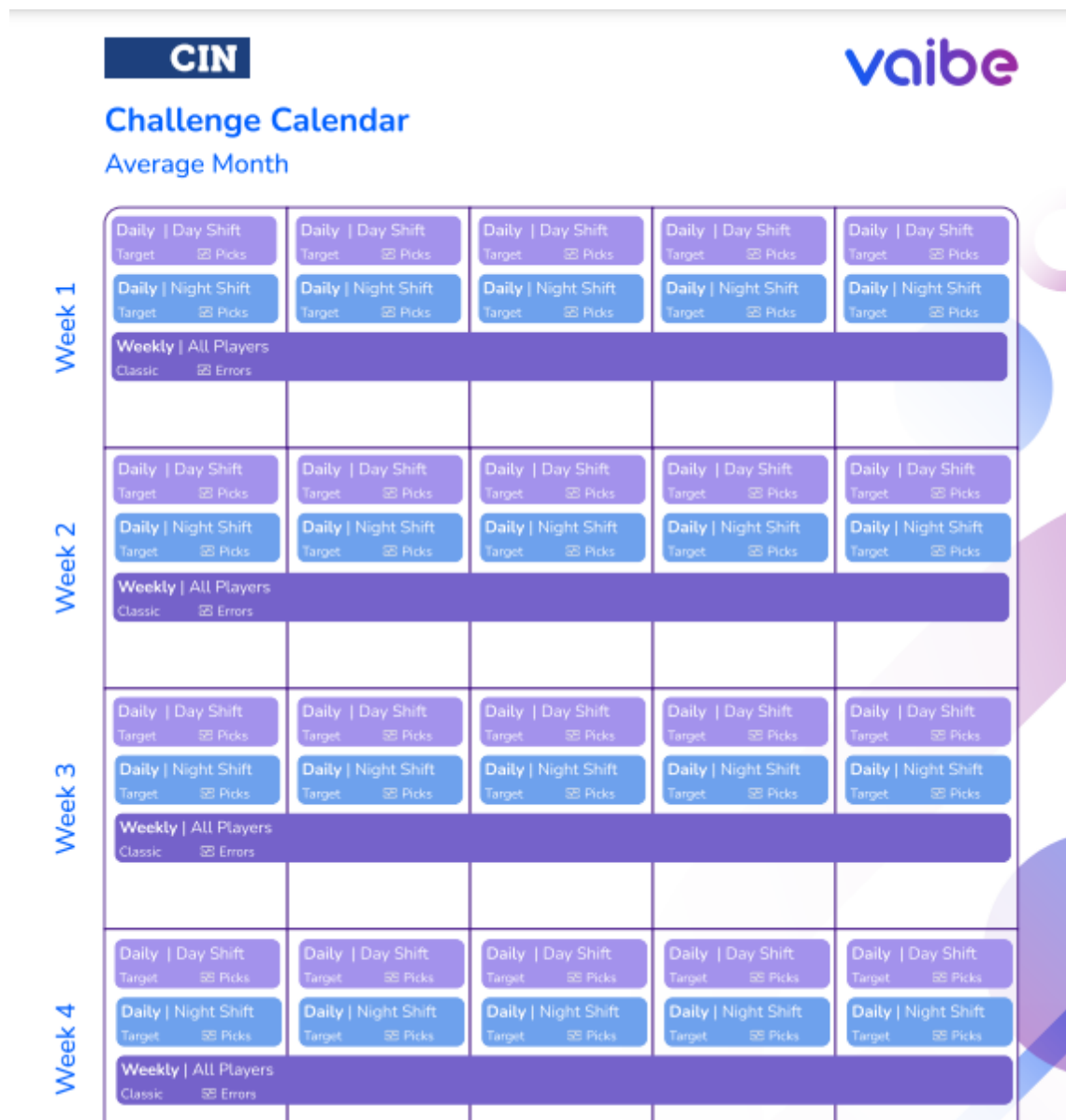


Figure F.2: Game plan average month proposal: Daily shift picks challenge; Weekly error logging challenge

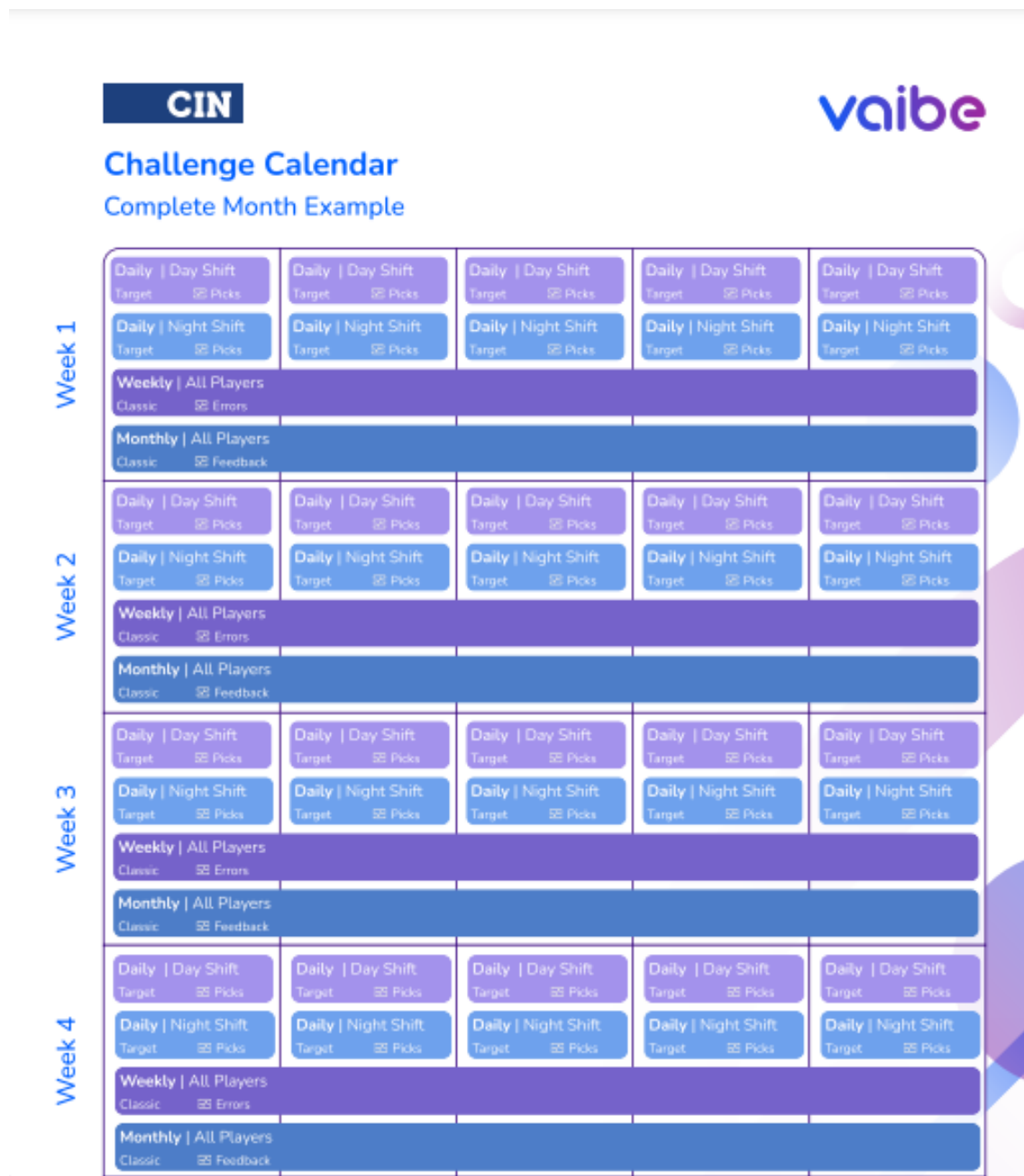


Figure F.3: Game plan complete month proposal: Daily shift picks challenge; Weekly error logging challenge; Monthly feedback challenge