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Optimization of a Warehouse Management System based on a Personal Digital Assistant

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Optimization of a Warehouse Management System based on a Personal Digital Assistant

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A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science, Specialisation Area of Software Engineering

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Porto, September 17, 2024

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Abstract

In today's fast-paced landscape of warehouse management, the increasing complexity of logistics requires the implementation of advanced technological solutions to ensure operational efficiency and accuracy. This thesis centers on the integration of a Personal Digital Assistant with barcode scanning and real-time data synchronization to optimize warehouse operations. Through automation and seamless connection with current systems, the suggested system offers improved accuracy and efficiency in critical areas including product picking, stock management, and order fulfillment.

The proposed solution aims to minimize human errors, streamline inventory tracking, and improve overall workflow by incorporating mobile scanning devices and modern data capture technologies. Throughout the project, user-centric design and system scalability were prioritized.

The experimentation phase involved testing in real warehouse environments to validate the effectiveness of the system, demonstrating a significant reduction in picking times and increased accuracy in stock management.

Lastly, the deployment of the system based on Personal Digital Assistants has shown efficacious in resolving crucial warehouse activities, diminishing errors, and enhancing order processing and inventory management in terms of speed and accuracy. Operational effectiveness and technology integration are critical in today's business climate, and the system that has been designed gives companies the tools they need to meet these difficulties and stay ahead of the competition.

Keywords: Warehouse management, Warehouse Operations Optimization, Personal Digital Assistants, Barcode Scanning, Mobile Scanning Devices

Resumo

Atualmente, na área de gestão de armazéns, a crescente complexidade da logística exige a implementação de soluções tecnológicas avançadas para garantir eficiência operacional e precisão. Esta dissertação centra-se na integração de um Assistente Pessoal Digital, através da digitalização de códigos de barras e sincronização de dados em tempo real, com o objetivo de otimizar as operações de armazém. Através da automação e da ligação com os sistemas existentes, o sistema proposto oferece maior precisão e eficiência em áreas cruciais, como a organização de produtos pelas respetivas encomendas, a gestão de stock e o cumprimento de *leadtimes* das mesmas.

A solução proposta tem como objetivo minimizar erros humanos, simplificar a rastreabilidade de inventários e melhorar o fluxo de trabalho geral, incorporando dispositivos móveis de digitalização e novas tecnologias de captura de dados. Ao longo do projeto, foram priorizados o design centrado no utilizador e a escalabilidade do sistema.

A fase de validação e experimentação, envolveu testes em ambientes reais de armazém para validar a eficácia do sistema, demonstrando uma redução significativa nos tempos de *picking* e um aumento da precisão na gestão de stock.

Por fim, a implementação do sistema baseado em Assistentes Pessoais Digitais mostrou-se eficiente na resolução das atividades principais do armazém, reduzindo erros e melhorando o processamento de encomendas e a gestão de inventário das mesmas. A eficácia operacional e a integração tecnológica são essenciais no clima empresarial atual e o sistema projetado oferece às empresas as ferramentas necessárias para enfrentar esses desafios, superando a concorrência.

Palavras-Chave: Warehouse management, Warehouse Operations Optimization, Assistente Pessoal Digital, Barcode Scanning, Mobile Scanning Devices

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Acronymous and Symbols

List of Acronymous

API	*Application Programming Interface*
ADB	*Android Debug Bridge*
ERP	*Enterprise Resource Planning*
EAN13	*European Article Number*
HCI	*Human-Computer Interaction*
PC	*Personal Computer*
PDA	*Personal Digital Assistants*
QR Code	*Quick Response Code*
RFID	*Radio Frequency Identification*
RMA	*Return Merchandise Authorization*
SC	*Supply Chain*
SDK	*Software Development Kit*
SELinux	*Security-Enhanced Linux*
SQL	*Structured Query Language*
UART	*Universal Asynchronous Receiver-Transmitter*
WMS	*Warehouse Management System*

1 Introduction

The goal of this chapter is to present the primary focus of this thesis, which centers on examining and creating a warehouse management system based on a Personal Digital Assistant (PDA).

The section on Contextualization provides an overview of the project's background and justifies the necessity for Kontrolsat to adopt an advanced solution that incorporates PDA technology to improve its warehouse operations. The Analytical and Ethical Interpretation will examine the impact of the solution from the perspectives of key stakeholders.

In the Objectives section, the key goals for improving warehouse processes will be specified. The iterative and evolutionary approach used to create and improve the system will next be described in the Methodology section.

The Research Methodology will follow, outlining the research questions, and the systematic approach used for the literature review and analysis. Lastly, the structure of the document will be explained, outlining all the chapters of the thesis.

1.1 Contextualization

The use of Personal Digital Assistants (PDAs) in warehouse management is a widespread practice across industries, known for significantly enhancing the efficiency and accuracy of inventory and order fulfillment processes. PDAs equipped with barcode scanners, location tracking, and real-time data capabilities provide essential tools for ensuring that products are picked, packed, and shipped with minimal errors. With the expansion of industries and the rising complexity of logistics operations, dependence on such technology has become critical to retaining a competitive edge and achieving customers' high expectations for speed and dependability.

The logistics sector, despite its numerous technological improvements, is surrounded by a variety of obstacles. First among these problems is the need to guarantee the accuracy of product picking within environments where items are difficult to differentiate or are located in different areas. Products misplaced especially on pallets cause more delays when employees are looking for the right ones. Customer dissatisfaction and logistical issues abound when businesses cannot track their deliveries accurately. Kontrolsat, a company that handles domestic products from small to large, also faced similar logistical challenges. The initial approach of the company to order fulfillment relied on a simple mobile application that guided employees in picking smaller items but did not have advanced features to manage larger products or ensure accuracy in picking. Sometimes products are misplaced or incorrectly tracked, thus causing errors and delays very often. The absence of such a system hindered even more because there was no basic system for authentication of serial numbers for large items or tracking orders in real-time. Having identified these operational gaps, Kontrolsat embarked on searching for an advanced solution to improve its warehouse operations.

In response to these issues, Kontrolsat has tackled them directly by introducing a PDA with a built-in scanner. This device works as a central platform for all warehouse tasks, where employees can now scan barcodes and get product locations in real time. This ensures that item picking is done correctly, location confirmation is achieved, and serial numbers are captured, which is important for larger goods.

By giving instant information capture using barcode scanning and tracking where items are located, therefore PDA device will help in much lower error rate, enhancing the accuracy of picking as well as streamlining the whole order fulfillment process. Hence, with these capabilities, the system will enhance operational efficiency while meeting customer needs, allowing smoother logistics processes to drive improved overall performance.

In the provision of instant data acquisition, barcode reading, and position monitoring, errors will be effectively minimized, picking precision enhanced, and the whole ordering delivery procedure made simpler by using a PDA. With this, Kontrolsat can improve its operational effectiveness and satisfy clients’ needs hence making logistics smoother and overall performance better.

1.2 Analytical and Ethical Interpretation

Addressing the logistical challenges faced by Kontrolsat requires considering the interests of several key stakeholders, including warehouse staff, management, customers, and suppliers. Each of these groups is directly impacted by the efficiency and accuracy of warehouse operations.

The adoption of new technology, including the Personal Digital Assistant (PDA), is expected to increase job security and productivity for warehouse employees. The PDA lowers human labor and decreases errors by automating critical activities including picking, material reception, and product storage. This makes working conditions safer and more productive.

Reducing operational expenses, preserving a competitive edge, and optimizing procedures are management's top priorities. By centralizing warehouse operations and guaranteeing precise product tracking and data synchronization, the PDA satisfies these requirements.

Customers benefit from faster, more accurate order fulfillment. The improved accuracy of inventory management and order picking ensures timely deliveries and accurate product identification, resulting in higher customer satisfaction and fewer product returns.

Suppliers also gain from better communication and more efficient order processing. The improved flow of information between Kontrolsat’s systems and suppliers’ databases enables smoother operations and more predictable logistics.

These technological improvements extend beyond operational benefits, as they also carry ethical implications. Kontrolsat is responsible for maintaining accurate data records, providing safe working conditions for employees, and delivering reliable services to customers. The PDA helps fulfill these ethical obligations by reducing human errors, ensuring transparency in operations, and fostering a fair and safe work environment.

In summary, the introduction of PDA technology enhances warehouse operations, improves communication among all stakeholders, and upholds ethical business practices. The study has shown that by improving data capture and location tracking, Kontrolsat can increase its overall efficiency and effectiveness.

1.3 Objectives

It is crucial to carry out a case study on Kontrolsat to comprehend and solve its logistical problems. This provides a real-world context, making it essential not only to address theoretical aspects but also to apply practical solutions to the observed problems.

Kontrolsat would be an ideal scenario for investigating the intricacies of warehouse management and optimization strategies due to increased customer demand and the variety of products offered.

The central objective of this project was to improve the existing mobile application, by restructuring the design and all functionalities. Adapting the backend in Dart enables communication with all the software at the company, like, for example, SAGE and PRESTASHOP. Each of these procedures has its advantages and can be modulated to meet the peculiar needs and features of Kontrolsat activities. The main objectives declared were:

i. **Enhance Scanning and Data Capture Capabilities**: Create an app for devices that will be capable of advanced scanning functions for two-dimensional barcodes, and serial numbers, amongst others, thus facilitating accurate data entry and retrieval between various systems.

ii. **Optimize Warehouse Operations:** Improve the effectiveness and precision of warehouse processes such as picking, stocking, and inventory management. These encompass verifying all product locations, enhancing order-wise product organization, and very robustly controlling out-of-stock situations.
iii. **Improve Product Information Management and Accessibility:** Update all product information promptly and make sure it is accessible across the whole range of company systems including SAGE, and RMA as well as a central application that synchronizes them all together. The goal here entails recording all incoming products as well as updating existing ones in time.
iv. **Integrate and Enhance System Intercommunications:** Develop one centralized application that enables different company systems to communicate effectively and share real-time data which will lead to greater operational transparency and coordination.
v. **Establish Special Handling Procedures for Large Items:** Create specialized processes for handling, verifying, and dispatching large domestic products to guarantee safety measures on these items in question.

1.4 Methodology

The iterative and evolutionary process used in this thesis was created to satisfy the changing requirements of creating a PDA-based warehouse management system. Instead of following a strict framework, the process evolved through frequent interactions and ongoing client feedback, ensuring that each development phase effectively addressed the operational requirements.

Cycles were used to structure the development. This method made it possible to constantly evaluate the system and make real-time modifications to ensure that it continued to meet the warehouse's changing requirements. The approach's evolutionary nature meant that the system adjusted to new obstacles as new functionalities were added, and its iterative nature allowed for constant system improvement.

The first phase should focus on gaining a deep understanding of warehouse operations and identifying which processes could be improved. This phase also should include conducting the literature review, performing a thorough requirement analysis, and establishing the architectural design, which provides the foundation for the subsequent phases of development.

The system's back-end should be created in the second phase to gather crucial data and connect it with the business's current IT infrastructure. The initial development steps on the front-end interface need to be made as well.

The third phase should focus on finalizing the front-end system with an emphasis on user experience and usability. Additionally, the system should be evaluated to guarantee complete functionality and fulfill the operational needs of the warehouse workers, and bug fixes should be reviewed.

In the last phase that follows these development stages, the project should be thoroughly documented, including technical documentation on the system's design, functionality, and user manual. This documentation makes it easy to extend, expand, and manage the system in the future.

The system should be created using this flexible, iterative, and evolutionary methodology to satisfy current operating needs as well as future development and problems.

1.5 Research Methodology

The research methodology for this thesis was designed to ensure a thorough exploration of relevant studies, articles, and academic papers. The process was structured around specific research questions, guiding the selection and analysis of studies to ensure that findings were directly applicable to the development of a PDA-based warehouse management system. This section outlines the sources used, the selection criteria, and the overall approach adopted for the literature review.

The literature search was conducted using a combination of electronic databases and indexing services, chosen for their comprehensive coverage and academic rigor. These are some of the key databases and platforms used in this research:

- Google Scholar.
- ScienceDirect.
- Scopus.

These databases were selected for their authoritative content and broad scope, particularly in the fields of warehouse management, mobile technologies, and operations optimization. They offered access to peer-reviewed research, ensuring that only high-quality, credible sources were incorporated into the thesis.

1.5.1 Research Questions

The selection of studies was driven by specific research questions that aimed to focus the literature review on the most pertinent information to the project.

- What are the current trends and best practices in Warehouse Management Systems (WMS)?

- How have mobile technologies, particularly PDAs, influenced warehouse operations optimization?
- What role do barcode scanning and mobile scanning devices play in modern warehouse processes?
- How can system integration improve the efficiency of warehouse management?
- What case studies provide practical insights into the application of PDAs in inventory management?
- What technological challenges and solutions have been identified in real-world warehouse environments?

1.5.2 Selection Criteria

The selection of studies prioritized recent technological advancements, real-world applications, and optimization strategies for warehouse management. The research focused on publications from the period between 2005 and 2024. Although priority was given to more recent works, older publications were included when frequently cited by newer studies, highlighting their ongoing relevance. This approach ensured a balance between foundational theories and current innovations in the field.

The search was restricted to papers published in English to maintain a consistent standard for analysis and comprehension. Additionally, the inclusion criteria required that each study was directly applicable to the research objectives of this thesis.

To refine the scope of the literature review, carefully selected keywords were used, aligning closely with the research objectives, like:

- Warehouse Management.
- Warehouse Operations Optimization.
- PDA.
- Barcode Scanning.
- Mobile Scanning Devices.

This methodology ensured that the literature review was comprehensive, accurate, and directly relevant to the project's objectives.

1.6 Structure

This thesis is organized into seven chapters, each addressing a specific aspect of the development and analysis of a warehouse management system integrated with a Personal Digital Assistant (PDA).

The Introduction chapter provides an overview of the project, outlining the motivation and objectives behind the development of a PDA-integrated warehouse management system. It explains the research question and the methodology used throughout the study, including the ethical considerations and limitations that shaped the scope of the project.

The Theoretical Concepts and Literature Review chapter presents the theoretical foundations and reviews relevant literature concerning key areas such as Warehouse Management Systems (WMS), mobile technologies, barcoding, and system integration. This chapter also discusses how these concepts contribute to optimizing warehouse operations through automation and real-time data synchronization.

The Current System Description chapter provides an overview of Kontrolsat’s existing system, highlighting the current operational process and its limitations.

The Requirement Analysis chapter focuses on outlining the functional and non-functional requirements of the system, providing a comprehensive overview of the technological needs identified to improve efficiency in warehouse operations.

The System Architecture and Design chapter explores the architectural framework of the developed system, emphasizing the modular design of the PDA front-end and back-end components. It discusses how the system interacts with existing software and describes the database design and process workflows for managing warehouse activities.

The Implementation chapter focuses on the implementation of the process workflows within the warehouse management system. It highlights the interaction between users and the PDA-based system in real warehouse environments, demonstrating how the workflows were designed to optimize efficiency and accuracy.

The Experimentation and Evaluation chapter evaluates the system's performance through experimentation in a live warehouse setting, providing an analysis of the results and insights gained from the implementation.

The Conclusions and Future Work chapter summarizes the accomplishments of the project, addressing how the objectives were met and the key outcomes achieved. It also highlights the limitations of the current implementation and outlines potential future enhancements.

2 Theoretical Concepts and Literature Review

With the context established, the next chapter delves into the theoretical concepts and relevant research surrounding Warehouse Management Systems (WMS), Personal Digital Assistants (PDAs), barcoding and data capture technologies, system integration, and optimization methods. It provides a comprehensive understanding of current warehouse management technologies and their application in developing an efficient PDA-based solution for Kontrolsat. Through the exploration of advancements in WMS, mobile technology, and data capture systems, the chapter establishes a theoretical foundation for a more automated and integrated warehouse management process. Additionally, significant research and technological progress are highlighted, emphasizing the importance of system integration, real-time data acquisition, and Human-Computer Interaction (HCI) in optimizing warehouse efficiency.

2.1 Warehouse Management Systems

In modern warehouse operations, WMS have become indispensable tools for optimizing logistics by tracking inventory levels, managing stock locations, and streamlining the movement of products throughout the Supply Chain (SC). According to Connolly (2008), rugged handheld computers with wireless communication capabilities allow for real-time stock control, integrating seamlessly with wider software systems, which reduces the need for manual stock-taking processes. Furthermore, WMS often includes algorithms for storage location assignments that help coordinate logistics operations and improve overall resource management (Pereira et al., 2019).

The incorporation of advanced technologies such as PDAs and Radio Frequency Identification (RFID) systems has significantly enhanced warehouse management. As noted in the article Wang (2008), PDAs and RFID systems automate data capture, reducing human intervention and errors. These PDAs, equipped with Wi-Fi connectivity, enable employees to manage inventory, transfer products, and conduct stock audits more efficiently. Even in areas with weak Wi-Fi signals, these devices synchronize data between the local device and the central database, ensuring continuous operation (Gašpar V et al., 2011). The integration of mobile computing devices not only improves the accuracy of stock control but also contributes to streamlined operations (Dickman P et al., 2011).

Automated technologies such as barcode readers have further minimized manual intervention in warehouses. Click or tap here to enter text. highlights that automated barcode readers can record the entry and exit of products, potentially eliminating the need for regular stock audits. Traditionally manual processes like stock counting and barcoding, once essential for inventory management, have been significantly optimized by WMS implementations (Mohamed, 2019). This optimization ensures that goods are tracked, stored, and dispatched accurately, which is vital for maintaining customer satisfaction and SC efficiency (Pihir et al., 2011).

WMS has also transformed warehouse operations in high-demand industries such as e-commerce. Richards & Gwynne (2014) point out that WMS has evolved to handle the increased pressure for speed and accuracy in order processing, which is essential for e-fulfillment. Real-time updates to inventory databases minimize errors and contribute to smoother workflow management (Boissy et al., 2006). Moreover, integrating technologies such as RFID and barcoding with WMS further enhances inventory control, improves the flow of goods, and reduces operational costs (Borz & Proto, 2022).

Warehouse layout and the use of WMS are also crucial for optimizing the movement of materials from receipt to delivery. The article of Mohamud et al. (2023), explains that proper inventory management, product tracking, and storage space optimization are essential for reducing operational costs and improving customer satisfaction. The integration of WMS with mobile devices like PDAs enables companies to boost employee productivity and improve customer service levels (Coughlan & Breslin, 2003).

The role of WMS continues to evolve with the growing complexity of SCs. According to Klumpp & Loske (2021), WMS plays a critical role in maintaining accurate inventory levels, providing real-time data, and supporting the overall operational efficiency of warehouses. These systems have become the backbone of modern warehouse operations, ensuring that goods move through the SC with minimal errors and delays (Klongsungsorn, 2016).

As WMS continues to integrate advanced technologies such as RFID, barcoding, and PDAs, they remain central to the automation and optimization of warehouse operations. These systems not only improve operational efficiency but also contribute to reducing environmental impacts by minimizing manual processes and resource waste (Dickman P et al., 2011). Thus, the ongoing development of WMS will play a vital role in the future of warehouse management, supporting both economic and environmental sustainability.

2.2 Personal Digital Assistants (PDAs) in Industry

In recent years, Personal Digital Assistants (PDAs) have become crucial for enhancing the efficiency of warehouse and logistics operations. Designed to streamline data capture, inventory management, and real-time communication, PDAs have proven essential for modern warehouse environments. By integrating handheld devices with WMS, businesses have significantly improved accuracy, mobility, and productivity, allowing for optimized operations and reduced manual interventions. Connolly (2008) highlights that PDAs equipped with barcode scanners and RFID readers are widely used in stocktaking and order picking, offering versatile communication options in logistics like Bluetooth, Wi-Fi, and GPS/GSM.

PDAs have reshaped warehouse activities by incorporating human-machine interfaces into daily tasks. As Pereira et al. (2019) point out, PDAs are employed to improve processes such as picking and stocktaking. However, introducing such devices into the workplace can sometimes create uncertainty among employees (Gašpar V et al., 2011). Despite this, the benefits of PDAs are evident, as demonstrated in Click or tap here to enter text.Zhang X & Lian X (2008), where RFID-enabled PDAs like the Intermec 700 are used to read and write electronic tags, thus enhancing operational efficiency.

One of the key advantages of PDAs is their ability to provide rapid barcode scanning, improving accuracy in inventory checks. Tong (2023) explains how these devices enable quick and precise stocktaking. Furthermore, PDAs enhance worker mobility, reduce paperwork, and streamline processes like product intake, transfer, and inventory tracking, as outlined by (Gašpar et al., 2012) This flexibility makes it easier for companies to meet operational requirements effectively.

Additionally, PDAs provide real-time data access, which has become invaluable in modern warehouse environments. Pihir et al. (2011) emphasize that mobile barcode systems integrated with PDAs allow workers to update inventory systems in real-time, reducing delays and increasing accuracy. Similarly, Kai-hu H et al. (2009) points out that PDAs help logistics staff receive and track products in real-time, ensuring proper quality control before storage. This functionality is further supported by Wang (2008), where PDAs integrated with RFID readers aid in transmitting inventory data to centralized systems for better tracking and management.

The productivity boost from automated inventory systems enabled by PDAs is also significant. Zarina et al. (2007) describe how PDAs reduce the time spent on routine tasks like manual data entry, thus improving overall efficiency. Improving Business Logistics Using Barcode Scanners emphasizes the importance of using PDAs to cut costs and streamline processes in the competitive business environment. Ibach et al. (2005) also note that PDAs equipped with WLAN technology optimize warehouse operations by calculating positions based on environmental sensing.

Automated inventory systems enabled by PDAs also play a critical role in enhancing productivity. As described in Zarina et al. (2007), PDAs reduce the time spent on routine tasks like manual data entry, thus improving overall efficiency. In a competitive business landscape, Improving Business Logistics Using Barcode Scanners stresses the importance of using tools like PDAs to cut costs and improve processes. Additionally, Ibach et al. (2005) note that PDAs equipped with WLAN can optimize warehouse operations by calculating positions based on environmental sensing.

The growing demand for mobility and flexibility in warehouses has driven the rapid adoption of PDAs. Tserng et al. (2005) discuss the development of more powerful devices with broader applications, making PDAs indispensable across various industries. Moreover, Boissy et al. (2006) explain that PDAs with real-time data capture have reduced the need for manual input, thus increasing the accuracy and efficiency of inventory management.

PDAs have revolutionized warehouse operations by enabling real-time data capture and retrieval, improving the efficiency of tasks like inventory management and product picking. Richards & Gwynne (2014) mention that mobile computing devices, including PDAs, are essential for streamlining warehouse activities. Zhao et al. (2017), further support this by noting that PDAs facilitate mobile data entry and real-time updates, significantly enhancing operational efficiency.

Integrating PDAs with WMS is crucial for optimizing warehouse operations. Dickman P et al. (2011), details how handheld PDA scanners with wireless connectivity ensure seamless data flow between enterprise resource planning (ERP) systems and logistics platforms. Zingde & Shroff (2021), further add that barcode-equipped PDAs enable quicker decision-making, reducing delays in processing inventory.

Looking to the future, PDAs are expected to play an increasingly important role in warehouse environments. Coughlan & Breslin (2003), predict that modern handheld devices will replace older barcode scanning systems, providing greater flexibility and scalability. Radadiya (2017) also emphasizes that mobile PDAs are now essential for improving productivity and tracking product movements in real-time.

Finally, PDAs enhance decision-making in warehouse environments by providing real-time inventory tracking, according to Klumpp & Loske (2021) and Borz & Proto (2022). Their adoption helps businesses move away from manual data entry, thereby improving overall operational efficiency (Klongsungsorn, 2016).

2.3 Barcoding and Data Capture Technologies

Barcoding and data capture technologies have become foundational in warehouse and logistics operations, offering accurate product identification and efficient inventory tracking. Barcodes, including 1-D and 2-D codes, along with Radio Frequency Identification (RFID), enable fast and automatic data reading, enhancing processes like stocktaking and order picking (Connolly, 2008). These technologies, when integrated with mobile devices such as PDAs, further streamline data capture and improve overall processing times (Zhao et al., 2017).

One of the key advantages of barcoding systems is their ability to automate inventory management, reducing manual errors and improving operational efficiency. According to Mohamud et al. (2023), barcoding reduces human error by providing real-time updates on product movement and stock levels. This real-time data sharing between warehouse and central systems enhances inventory accuracy and operational speed (Pihir et al., 2011).

In particular, the use of 2-D barcodes, has simplified warehouse processes by offering more detailed data collection, which improves the accuracy of inventory audits (Tong, 2023). Handheld barcode scanners allow workers to speed up physical inventory tasks by instantly identifying product information, significantly reducing time spent on manual data entry (Gašpar et al., 2012).

Beyond traditional barcodes, RFID technology has revolutionized data capture by providing non-contact data exchange through radio-frequency signals. This technology enables faster and more accurate item tracking, particularly when integrated with PDA systems (Dickman P et al., 2011).

Integrating automatic identification and data capture (AIDC) technologies, such as barcoding and RFID, into warehouse operations has brought significant improvements in inventory accuracy and efficiency. These systems, when combined with mobile devices, reduce manual input errors and facilitate faster decision-making processes, as described by (Zingde & Shroff, 2021).

Barcoding systems also offer considerable cost savings by automating processes and minimizing the need for manual data entry. As noted by Tserng et al. (2005), barcode scanning has become an essential tool for various SC applications, improving both speed and accuracy. The real-time data collection enabled by these systems ensures that inventory systems are updated instantly, as further supported by Boissy et al. (2006), improving both accuracy and efficiency across operations.

In conclusion, barcoding and data capture technologies remain essential in modern warehouse management. By integrating with RFID and PDAs, these systems reduce operational errors and enhance real-time tracking, contributing to faster, more accurate workflows across the SC. As businesses continue to refine these integrations, the future of warehouse management will likely see ongoing improvements in speed, accuracy, and overall efficiency.

2.4 System Integration in Warehouse Environments

The complexity of modern warehouse operations demands seamless communication between various technologies to ensure operational efficiency and accuracy. Integrating barcoding, RFID, and ERP systems plays a crucial role in unifying these operations, facilitating real-time data sharing, and improving decision-making processes. As described by Connolly (2008), combining label-reading technologies with advanced software systems enables comprehensive management of inventory, purchasing, and ERP, thereby enhancing transparency and control across all warehouse activities.

A robust network infrastructure is essential for successful system integration, particularly in large warehouses where materials and complex layouts can obstruct signals. As noted in (Gašpar V et al., 2011), establishing strong wireless access points ensures reliable communication between mobile devices and backend systems, thus minimizing operational disruptions.

Moreover, the integration of RFID-enabled mobile devices with centralized systems facilitates automatic data storage, querying, and management. This real-time communication between mobile systems and ERP databases ensures that inventory information is updated accurately, as highlighted by Zhang X & Lian X (2008). ERP integration plays a pivotal role in optimizing inventory placement and enhancing operational efficiency, as described by Tong (2023).

Data synchronization between mobile barcode systems and ERP platforms significantly reduces errors, improving overall SC visibility (Pihir et al., 2011). Real-time data sharing not only enhances accuracy in inventory tracking but also supports fluid communication across multiple systems, enabling faster, more informed decision-making (Kai-hu H et al., 2009).

Another significant benefit of system integration is automated data management. Combining barcode scanners with Structured Query Language (SQL) based databases, for instance, enables the automatic processing of inventory data, reducing manual intervention and improving accuracy (Zarina et al., 2007). Converting barcode data into actionable insights further streamlines warehouse operations (Garg, 2012).

Location tracking and the precise movement of goods are further optimized through integrated systems. The combination of barcode scanning and WMS enables real-time tracking of items, reducing errors in inventory management (Ibach et al., 2005). Extending this integration beyond warehouses to job sites enhances the efficiency of data collection, broadening the reach of SC management (Tserng et al., 2005).

Real-time synchronization is critical for inventory accuracy. By integrating mobile systems with central databases, all departments are synchronized, allowing real-time updates that improve inventory tracking and decision-making (Boissy et al., 2006). This also facilitates greater operational transparency, as each stakeholder can access up-to-date information across various systems (Richards & Gwynne, 2014).

Additionally, middleware platforms are instrumental in enabling the integration of previously isolated applications. Middleware allows for smoother coordination between warehouse functions and back-office systems, streamlining operations and extending business processes into the warehouse environment (Dickman P et al., 2011).

The integration of business intelligence systems with ERP platforms ensures better visibility across the SC. This enhanced visibility allows for more accurate stock monitoring, improving decision-making across departments (Zingde & Shroff, 2021). The importance of reliable wireless connectivity in maintaining real-time data flow between mobile devices and central servers is also emphasized (Coughlan & Breslin, 2003).

Overall, the integration of WMS, ERP, and mobile devices minimizes inefficiencies, improving productivity across warehouse operations (Klumpp & Loske, 2021). Real-time data flow between these systems helps reduce data inaccuracies, ensuring consistent data sharing that supports optimal decision-making (Borz & Proto, 2022).

Finally, the seamless integration of various systems—such as ERP, WMS, and mobile devices—enhances transparency and improves overall warehouse efficiency. This integration enables more informed decisions and smoother operational processes, ensuring a more cohesive and efficient warehouse environment (Klongsungsorn, 2016).

2.5 Picking and Inventory Management Optimization

Optimizing picking and inventory management processes is fundamental to achieving efficiency in warehouse operations. A crucial aspect of picking optimization is knowing the precise location of stored items. As Connolly (2008) explains, that assigning unique addresses to each shelf and rack in a warehouse, recorded in a centralized database, enables quick and accurate retrieval of products. The development of localization systems has further reduced the time spent searching for items, one of the most time-consuming aspects of picking (Pereira et al., 2019).

The integration of barcode scanners and RFID technology has transformed key processes in warehouse management, such as intake, transfer, and stock control. Barcode systems, for instance, are recognized for their ability to speed up inventory tasks (Gašpar V et al., 2011), while RFID systems aid in tracking goods, improving both product movement and inventory accuracy (Zhang X & Lian X, 2008). These technologies ensure that data capture is more accurate, and workflow efficiency is enhanced.

Further optimization can be achieved through algorithm-based route planning, which determines the most efficient paths for picking, thereby reducing the time and energy spent on these tasks (Tong, 2023). Technologies such as barcode scanning improve the speed of data entry and inventory management by automating manual tasks, thereby reducing human error and enhancing operational efficiency (Gašpar et al., 2012). As automated systems increasingly replace traditional inventory methods, they eliminate much of the time and resource waste associated with manual processes (Mohamed, 2019).

The implementation of mobile barcode systems has drastically minimized errors and sped up order fulfillment. As noted by Pihir et al. (2011), these systems significantly enhance inventory management by ensuring real-time data capture, reducing both delays and mistakes. Additionally, real-time tracking with mobile devices, as highlighted by Kai-hu H et al. (2009), allows warehouse staff to perform tasks like receiving and stock management more efficiently, further improving warehouse operations.

Real-time inventory tracking is vital to maintaining warehouse efficiency. Mobile devices that track inventory movement in real-time have been shown to reduce errors and optimize stock control processes (Wang, 2008). Testing and evaluating inventory systems, as described by Zarina et al. (2007), allows for comparison between traditional records and system-generated data, helping to ensure operational accuracy.

Barcode scanning technology plays a critical role in improving the speed and accuracy of data capture during the picking process. Scanners convert barcode data into actionable information, thereby streamlining decision-making and improving workflow efficiency (Garg, 2012). Additionally, systems that print product lists and warehouse locations simplify the picking process by providing easy access to real-time data (Ibach et al., 2005), further reducing errors and increasing operational accuracy (Tserng et al., 2005).

Guiding employees to the correct product locations is another critical element of optimizing the picking process. Automated systems that assist workers in finding the correct items quickly reduce errors and shorten the time required to fulfill orders (Boissy et al., 2006). Real-time data from mobile devices further supports this process, allowing workers to retrieve products with greater speed and accuracy (Richards & Gwynne, 2014).

Mobile technology also ensures order accuracy by minimizing errors during product selection. Mobile systems provide real-time updates on inventory levels, optimizing the picking process and reducing mistakes (Zhao et al., 2017). The integration of RFID systems with ERP platforms has resulted in notable improvements in both order processing and stock management, contributing to a more streamlined and efficient warehouse operation (Dickman P et al., 2011).

The combination of automated systems, handheld devices, and barcode scanning has brought about significant improvements in both picking accuracy and operational efficiency. These integrated systems not only speed up order fulfillment but also reduce the risk of errors, ensuring that products are delivered accurately and on time (Zingde & Shroff, 2021).

Additionally, the implementation of automatic identification and data capture (AIDC) technologies ensures timely product deliveries while reducing human error (Radadiya, 2017).

Finally, the use of real-time data capture in mobile and automated systems reduces picking errors and improves fulfillment speed, resulting in more efficient warehouse operations. This real-time tracking capability minimizes the risk of mistakes during the picking process, contributing to higher operational accuracy (Mohamud et al., 2023). Optimized picking routes and real-time data from mobile devices enhance both the speed and accuracy of order fulfillment, supporting more efficient warehouse workflows (Klumpp & Loske, 2021).

Automating the picking process through handheld devices further reduces the time spent on order fulfillment, leading to a more streamlined operation (Klongsungsorn, 2016). This integration of automated systems and mobile technologies ensures that warehouse operations are both faster and more accurate, significantly reducing the likelihood of operational errors.

2.6 Human-Computer Interaction (HCI) in Warehouse Technologies

Human-Computer Interaction (HCI) plays a pivotal role in enhancing the usability and efficiency of warehouse systems. The adoption of intuitive interfaces and user-friendly designs allows warehouse employees to perform their tasks more efficiently while minimizing errors. Wearable technologies, such as headsets and wireless belt-mounted computers, help workers move freely and complete their tasks without being hindered by traditional tools like clipboards, as noted by Connolly (2008). These hands-free solutions significantly improve the speed of operations and streamline workflows within the warehouse.

Visual management tools like barcode scanning systems have simplified validation processes during picking operations. As mentioned by Pereira et al. (2019), systems that incorporate mapping and tagging ensure that workers can quickly scan locations to confirm the accuracy of their picks, which ultimately improves efficiency and reduces mistakes.

User-friendly graphical interfaces are critical to ensuring that warehouse employees can easily interact with these systems. Simplified interfaces, designed for ease of use, allow workers to use new technologies practically. As outlined in the (Gašpar V et al., 2011), handheld RFID systems bring convenience to data handling processes. These systems are designed with the user in mind, emphasizing the need for flexibility and seamless navigation within warehouse operations.

Systems designed for semi-automated warehouse processes must offer flexibility in their interfaces to accommodate various operational levels. notes that flexible interfaces allow operators to effectively manage inventory at different stages, while Gašpar et al. (2012) emphasize that graphical user interfaces (GUIs) with clear transitions between orchestrations can significantly enhance user interaction and operational fluidity.

Vision sensors and advanced input systems also play an essential role in simplifying data collection. Mohamed (2019) explains how such systems can capture product codes through digital imaging, streamlining data entry and minimizing errors. The adoption of mobile devices, such as PDAs, has helped reduce the learning curve for workers, allowing them to quickly adapt to new systems and improve overall operational efficiency (Pihir et al., 2011).

Moreover, system accessibility is further improved by translating operating systems into native languages and simplifying tasks like scanning and system recovery, as pointed out by Kai-hu H et al. (2009). This ensures that the technology can be used by workers of varying technical expertise. Ensuring that interfaces are intuitive and require minimal training time is essential for warehouse workers. Wang (2008) highlights that intuitive interface design reduces training time and enhances overall system adoption, allowing workers to quickly become proficient in using the technology.

The importance of selecting the appropriate scanning technology—whether hands-free or handheld—based on the specific needs of the environment is emphasized by Garg (2012). This decision directly impacts user interaction and operational efficiency. Tserng et al. (2005) further highlight how pen-touch interfaces are particularly useful for on-site engineers who need to input data in demanding environments, such as when wearing gloves.

As Boissy et al. (2006) emphasize, user-friendly interfaces not only reduce training times but also enhance worker productivity. Similarly, Richards & Gwynne (2014) point out that intuitive mobile devices are essential for the smooth adoption of new technologies, leading to fewer errors and improved operational efficiency.

To minimize operational errors, mobile devices used in warehouse environments should require minimal training and offer intuitive user interfaces, as detailed in the case study by Dickman P et al. (2011). Systems that are easy to use ensure a smoother transition to new technologies, enhancing both worker productivity and operational outcomes.

Finally, as noted by Zingde & Shroff (2021), the simplification of warehouse operations through intuitive handheld devices has resulted in increased productivity and fewer operational disruptions. Developing user-friendly applications for tasks like product checking and label printing is crucial for maintaining efficient warehouse operations (Coughlan & Breslin, 2003). These principles are further supported by Mohamud et al. (2023) who emphasize that intuitive interfaces help reduce training times and improve worker productivity.

In conclusion, HCI principles, particularly those focused on intuitive design and usability, play a critical role in warehouse operations. User-friendly mobile interfaces are essential for the successful adoption of new technologies, as highlighted by Klumpp & Loske (2021), and help reduce errors while improving overall productivity. Borz & Proto (2022) underscore that intuitive interfaces reduce the time required for training, enabling workers to interact with systems more effectively and efficiently, thus improving overall workflow.

2.7 Stock Management and Replenishment Systems

Stock management and replenishment systems are critical for maintaining optimal inventory levels in warehouses while minimizing errors and delays. Automated technologies, such as RFID readers and barcode scanners, play a fundamental role in tracking products as they move in and out of the warehouse. Connolly (2008) highlights that these technologies reduce the need for manual stocktaking and enhance the accuracy of order picking by automatically recording stock movements.

A key advantage of modern inventory systems is their ability to trace stock movements, enabling the identification and resolution of inconsistencies. Pereira et al. (2019) emphasize that every movement of stock is recorded, allowing for improved accuracy in stock management through easy traceability and verification.

The use of barcode scanning technologies accelerates the stocktaking process, enhancing the efficiency of physical inventory management. As discussed at the Gašpar V et al. (2011), barcode scanners expedite stocktaking tasks, while RFID systems, as noted in Zhang X & Lian X (2008), further streamline stock management by providing accurate, easily accessible data.

For businesses with limited resources, semi-automated stocktaking systems offer an efficient alternative to fully automated solutions. Tong (2023)points out that these systems allow small and medium-sized businesses to conduct inventory checks with greater accuracy, even without comprehensive RFID infrastructure, thus optimizing operational costs.

Modular systems designed for intake, expenditure, and the transfer of goods further enhance flexibility in stock management. Gašpar et al. (2012), highlight the versatility of these systems, which allow businesses to tailor stock management to their specific needs, improving overall efficiency.

Real-time stock updates, facilitated by mobile barcode systems, are essential for improving inventory accuracy. As discussed by Pihir et al. (2011), these systems enable instantaneous stock updates, enhancing replenishment processes, particularly in multi-warehouse environments. Kai-hu H et al. (2009), similarly emphasizes the benefits of real-time monitoring across different warehouse locations.

The integration of RFID and PDA technologies supports automated replenishment by enabling real-time tracking of stock levels, thus minimizing discrepancies. Wang (2008) explains that continuous inventory updates provided by these systems reduce errors and enhance the efficiency of stock management processes. Similarly, Zarina et al. (2007) note that replenishment can be automated by adjusting stock quantities in the database based on real-time data.

Barcode scanning, widely used across industries, plays a significant role in capturing stock data quickly and accurately. Garg (2012) underscores the importance of these technologies for efficient stock tracking, while Ibach et al. (2005) highlight the benefits of real-time stock tracking for ensuring optimal storage space usage and simplifying complex stock relocation scenarios.

Mobile inventory management systems provide real-time visibility of stock levels, allowing for more effective replenishment. Tserng et al. (2005), note that mobile systems improve the tracking of material status, ensuring better control over stock. Boissy et al. (2006) further emphasize that automatic replenishment based on predefined thresholds prevents stockouts, improving inventory management.

Real-time stock tracking through mobile devices has been shown to optimize inventory management. Richards & Gwynne (2014) highlight the improvements in replenishment processes made possible by mobile technologies, while Zhao et al. (2017) note that integrating these devices with inventory systems automates stock replenishment, maintaining optimal inventory levels.

The integration of RFID with ERP systems, as described in the case study (Exploiting RFID in a Challenging Environment: A Commercial Case Study of Plant Rental and Intermittent-Wireless Hand-Held PDA-Based Scanners (2011), provides businesses with better visibility and control over stock levels. Real-time data tracking ensures that replenishment is timely, reducing stockouts and maintaining balanced stock levels, which is critical for operational efficiency.

Zingde & Shroff (2021), emphasize that real-time tracking through barcodes and mobile devices prevents stock shortages by providing constant updates on stock levels, allowing for timely replenishment. Similarly, Coughlan & Breslin (2003) highlight the benefits of real-time stock adjustments made directly from the shop floor, ensuring accurate and up-to-date inventory data.

Mobile devices play a crucial role in maintaining consistent stock levels, reducing the risk of stock shortages. Radadiya (2017) points out that real-time inventory tracking helps prevent stockouts by ensuring that stock levels are continuously updated. This point is reinforced by Mohamud et al. (2023), who highlight real-time tracking as a key factor in optimizing stock replenishment and warehouse efficiency.

Real-time inventory tracking is essential for maintaining warehouse efficiency and avoiding stockouts. Klumpp & Loske (2021) stress the importance of timely stock replenishment enabled by real-time tracking, ensuring that stock levels remain optimal. Additionally, Borz & Proto (2022) and Klongsungsorn (2016), underscore how mobile tracking systems reduce the likelihood of stock shortages by providing continuous updates on inventory status.

In conclusion, ensuring that stock levels are consistently updated through real-time tracking is critical for maintaining warehouse efficiency. As noted by Klongsungsorn (2016), real-time tracking using handheld devices ensures accurate stock levels, timely replenishment, and the overall effectiveness of stock management processes.

3 Current System Description

Based on the theoretical concepts discussed previously, this chapter delves into the practical application of those concepts by exploring the current system at Kontrolsat.

The main elements of the current system are described in this chapter, which begins with an overview of the integrated network of hosted and on-premise servers that support the company's primary functions. Additionally, it will examine the warehouse's operational procedures and their limitations, pointing out areas in need of improvement.

3.1 System Components Description

Beginning with the on-premise server that hosts critical systems for billing and order management to the sophisticated setup of hosted servers for customer interactions and e-commerce operations, each element is crucial for the daily activities at Kontrolsat. The functions played by each server and how they operate together to provide a unified and effective operating architecture will be covered in detail in the following sections. This methodical approach serves not only the needs of the present but also the strategic objectives for future expansion and improved system capabilities.

The System Components Diagram, as shown in Figure 1, illustrates the complex interplay between various software components and servers.

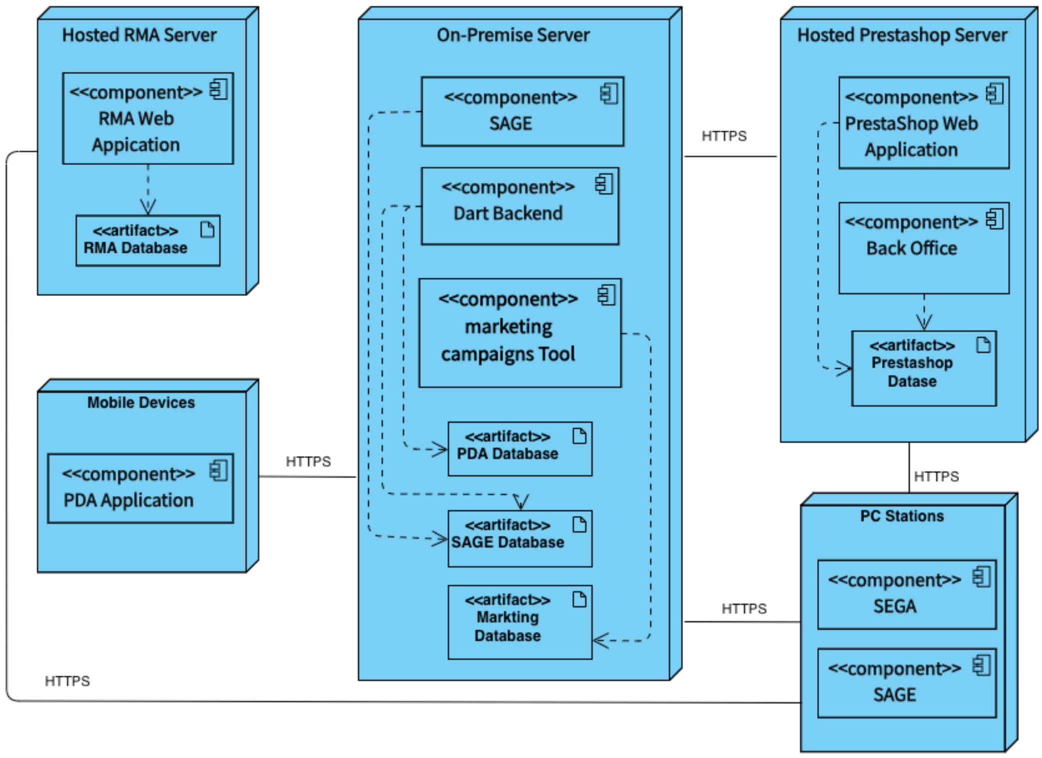

Figure 1 – System Components Diagram

3.1.1 On-Premise Server

The company's on-premise server (a Personal Computer (PC) running Windows) hosts the billing system database, a Dart backend, and software tools for analyzing sales for marketing campaigns. It also supports several databases, primarily SQL Server, crucial for daily operations.

I. SAGE

SAGE is a vital billing software used to record all types of operational transactions, from real-time stock levels per product to invoicing each sale. It also manages data related to suppliers and customers. SAGE stores its data in an SQL Server database to guarantee that every transaction is duly documented and to facilitate the smooth processing of orders, this SQL Server database is hosted on an on-premise server.

II. Dart Backend

This backend currently supports the mobile application by displaying order information to facilitate the picking process. It connects with PrestaShop to display the products of the orders and with SAGE to retrieve essential product information.

3.1.2 Hosted Servers

The hosted servers provided by Kontrolsat are crucial for increasing operating capacities. Critical applications for customer service, product returns, and incident management are hosted on these remotely managed servers. This section describes how each server contributes to the smooth operation of critical services such as PrestaShop and the Return Merchandise Authorization (RMA) system, emphasizing how they are integrated into our network architecture.

I. RMA

The Return Merchandise Authorization (RMA) system is hosted on the first of the externally hosted servers managed by WEBHS, which is less powerful. This PHP-Symfony framework application is used for registering all product serial numbers and managing incidents, storing detailed records in a MySQL database. This setup is essential for quality control, tracking, and handling any issues with supplier deliveries or customer returns, ensuring that items are correctly logged and managed.

II. PrestaShop

The second server, a high-capacity and powerful server, hosts the company's main e-commerce platform developed with the PHP - PrestaShop 1.7 framework. This comprehensive setup includes the front end, back end, and back office, along with its database. It handles all online transactions, customer interactions, and product information management, designed to ensure robust performance and reliability to accommodate high-traffic and complex data transactions.

3.1.3 Integration with Other Software

This section explores additional software tools that play vital roles in enhancing the operational efficiency at Kontrolsat. These tools support various facets of the company's daily operations, from order visualization to process management and billing.

I. **Flutter Front End**

Each mobile device at Kontrolsat is equipped with an application developed using Flutter (Dart), enabling staff to access and review pending orders and their specific details. This application is one of the systems that will be updated to improve its functionality and user experience. Its primary interface is with the Dart backend.

II. **TRELLO**

Kontrolsat is using TRELLO to coordinate all business operations on a digital Kanban board. Through the efficient management of duties like material intake, project oversight, and incident handling, this technology improves departmental collaboration and transparency. TRELLO's Kanban boards are visually appealing, which facilitates workflow management and guarantees timely and effective completion of tasks.

I. SEGA Shipping Manager

The SEGA Shipping Manager, which is hosted on each PC in the organization, is essential for completing order processing. Transport guidelines are important documentation attached to shipments that help with shipping operations, and this software creates them. These guidelines guarantee the precise recording of logistical details, including carrier information and delivery schedules, facilitating the order's efficient dispatch and delivery.

3.2 Current Operational Process

The company operates two warehouses: large products are stored in the second warehouse, while smaller and medium-sized products are kept in the main warehouse. The main warehouse consists of 6 aisles over two floors. Each aisle has 6 racks on each side, and each rack contains 4 shelves (arranged from bottom to top). The second warehouse, which houses large domestic products, has only one floor with 3 racks, as well as designated areas on the ground for organizing these larger items. Orders for large domestic products must be handled in the second warehouse, while smaller items are processed in the main warehouse. Therefore, if an order contains both large and small products, it is treated as two separate orders for fulfillment.

Orders placed on Kontrolsat's website are updated to a "paid" status once the payment is confirmed. In the main warehouse, these paid orders appear on the mobile application, allowing employees to view the specific products associated with each order (though the current system only allows viewing, without any further interaction or control within the application). Once all products scattered throughout the warehouse are picked, the shipping and invoicing processes begin. This is handled using the SEGA Shipping Manager, where all product serial numbers are scanned, and SEGA communicates with the RMA system to record this information for any future incidents. The shipping guide is then generated and affixed to the packaging containing the products.

As for material reception, after receiving products, all relevant information, including serial numbers and quantities, must be manually entered into both the SAGE and RMA systems. This manual process requires significant effort. Additionally, a record of the reception is manually added to TRELLO. The status of all orders is managed through PrestaShop.

As described, large domestic products are managed solely in the second warehouse. Since there is no invoicing station in the second warehouse, the invoice and shipping guide are generated in the main warehouse. When the employee reaches the second warehouse, the large product is dispatched based solely on the employee’s visual verification, without the aid of any scanning or digital validation to confirm the product's identity.

3.3 Current Limitations

The current mobile application at Kontrolsat, while offering limited functionality, still presents significant operational challenges. The present limitation of warehouse management is that users can only view the products linked to each order. Several inefficiencies that directly affect operational effectiveness and customer satisfaction have resulted from this limited functionality:

1. **Absence of Product Verification During the Picking Process**: The picking process occurs without any verification during its execution, which leads to mistakes. There are many similar products, which often confuses the staff.

2. **Inaccurate Stock and Location Tracking**: The existing system does not provide precise tracking for product locations or stock level verification. There are differences between the stock levels reported by the system and the real inventory in the warehouse since users are unable to precisely track which products are in particular locations of the warehouse. This inefficiency has increased operating costs by causing confusion and delays throughout the selection process.

3. **Limited Management of Large Items**: There is no efficient control or verification mechanism in place at the secondary warehouse, which is used for large home products. The lack of a reliable tracking system for these bulky commodities makes inventory and shipping management more difficult, perhaps resulting in orders including these products being mishandled.

4. **Limited Integration with External Systems**: The current system does not fully integrate with other key business systems, resulting in unsynchronized data across multiple software platforms.

5. **Inadequate Out-of-Stock Management**: The existing system does not support proactive out-of-stock management. Employees lack a systematic method to handle supply shortages, which prolongs order fulfillment times and encourages reactive rather than proactive stock restocking. This shortcoming usually causes orders to be incomplete or delayed, which hinders customer service.

6. **Lack of Operational Oversight**: The technology is unable to verify who has completed specific tasks or provide thorough tracking of warehouse activities. It is challenging to monitor performance, keep employees accountable, and efficiently manage warehouse procedures when there is a lack of operational visibility.

These constraints emphasized the necessity for a fresh system that combines cutting-edge tracking technologies to enhance stock management and operational transparency.

4 Requirements Analysis

Building on the analysis of the current system in the previous chapter, this chapter focuses on defining the requirements for the new warehouse management solution. Both functional and non-functional requirements essential for optimizing the system are outlined. An in-depth understanding of the system's needs is provided, highlighting ways to address operational inefficiencies and identifying key areas for improvement.

The functional requirements are based on specific use cases designed to enhance workflow, while the non-functional requirements focus on ensuring the system operates effectively and efficiently.

4.1 Functional Requirements

As functional requirements for the new system, a series of use cases were developed to comprehensively address the challenges and limitations of the existing warehouse operations. These use cases serve as the foundation for the system's design, each targeting key operational inefficiencies that were identified during the analysis of current processes.

The use case diagram below (Figure 2), illustrates the primary interactions between the system and its actors, as well as the dependencies among the various use cases identified for the warehouse management system.

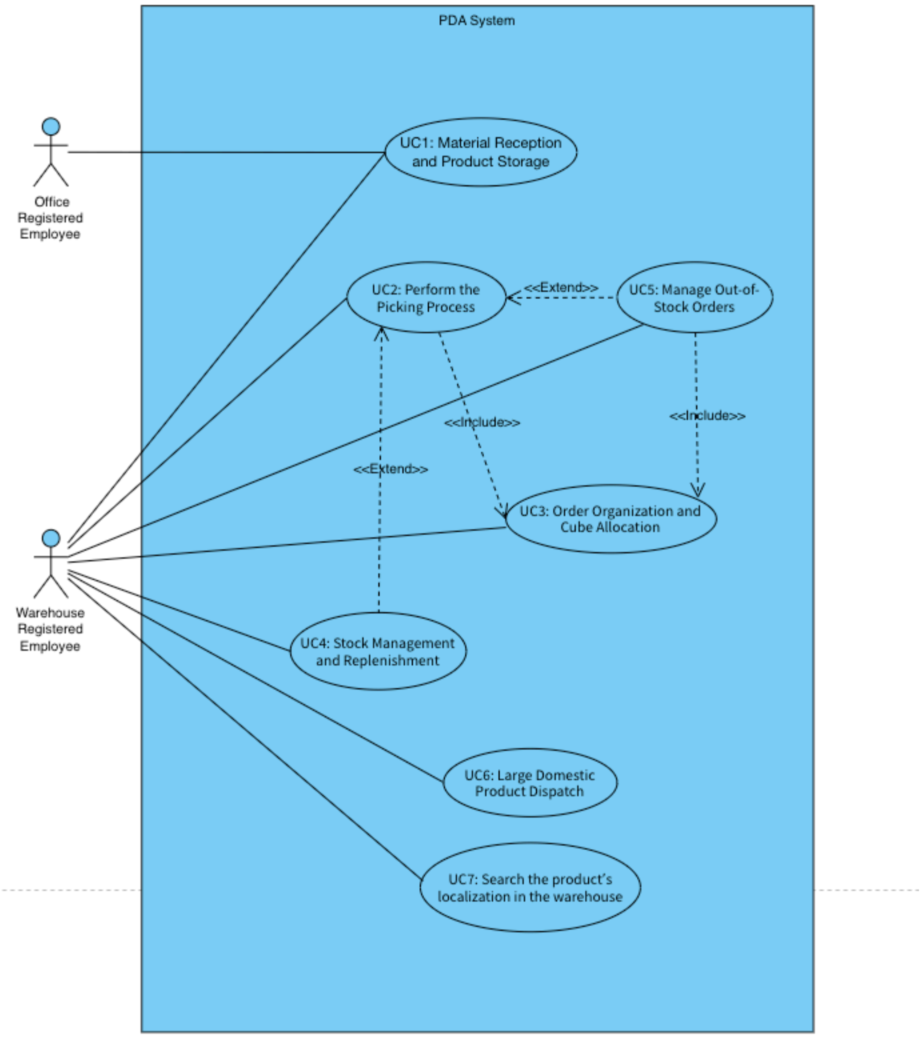

Figure 2 – Use Case Diagram

Actors:

- **Office Registered Employee**: This registered actor interacts specifically with the Material Reception and Product Storage use case. Their role is primarily administrative, overseeing the data verification and update process after materials are received. They do not participate in other hands-on warehouse operations.

- **Warehouse Registered Employee**: These registered employees are the primary users of the PDA system and are responsible for executing nearly all the processes. They interact with use cases such as Material Reception and Product Storage, Perform the Picking Process, Order Organization and Cube Allocation, Stock Management and Replenishment, Order Organization and Cube Allocation, Manage Out-of-Stock Orders, Large Domestic Product Dispatch, and Search the Product's Localization in the Warehouse. This makes them central to warehouse operations, as they handle physical products, stock updates, and order dispatch.

UC1: Material Reception and Product Storage

This use case begins with the capture and recording of all incoming materials at the point of reception. Products are scanned to identify and verify details, and immediate data synchronization occurs, facilitating the tracking of products and associated invoices. Following this, warehouse staff are notified to store the processed products.

Acceptance Criteria:

- The product needs to be identified with a scan, and the scan of the serial numbers must be recorded.
- Notifications need to be sent to warehouse staff to store products upon successful reception and verification.
- The location of the products to be stored needs to be recorded.

UC2: Perform the Picking Process

Streamlines the picking process through the scanning and validation of both Quick Response (QR Code) codes and barcodes, ensuring correct product retrieval and minimizing errors.

Acceptance Criteria:

- Employees need to verify the products by scanning them.
- The orders should be addressed to a registered user.

UC3: Order Organization and Cube Allocation

Uses a cube system with assigned QR Codes to organize and allocate products to specific orders.

Acceptance Criteria:

- All products within an order should be assigned to a cube without manual intervention.
- The cube allocation process should streamline order fulfillment.

UC4: Stock Management and Replenishment

Manages stock locations and quantities, enabling precise tracking and efficient replenishment actions based on real-time data.

Acceptance Criteria:

- Stock per location should be visible and easily trackable in the system.
- The system should detect the need to replenish stock.

UC5: Manage Out-of-Stock Orders

Implements a robust system for managing out-of-stock situations, alerting for stock discrepancies, and enabling quick response to prevent order delays.

Acceptance Criteria:

- Staff should be notified in real-time about stock discrepancies.
- Orders to be attributed out of stock should be selected by the system.

UC6: Large Domestic Product Dispatch

Establishes a new verification and tracking process for large domestic products, involving specialized handling and tracking measures.

Acceptance Criteria:

- The large domestic products need to be verified, and the serial number recorded.
- The tracking number should be recorded and presented to the client.

UC7: Search the Product's Localization in the Warehouse

Enables detailed visibility of product data and operations within the warehouse.

Acceptance Criteria:

- Product data, including their locations and quantities in each location, should be accessible in real time.

Dependencies and Extensions:

The diagram also shows the dependencies between various use cases, represented by dashed lines:

- **Perform the Picking Process**: This use case includes Order Organization and Cube Allocation, which always follow the picking process. It also extends to Stock Management and Replenishment and Out-of-Stock Management, meaning that during the picking process, stock replenishment or out-of-stock reporting may be triggered based on real-time data.
- **Manage Out-of-Stock Orders**: This use case plays a crucial role when handling products that are unavailable during the picking process. It includes Order Organization and Cube Allocation, ensuring that any missing items are appropriately flagged, and orders are adjusted accordingly.

4.2 Non-Functional Requirements

This system’s non-functional requirements are important because they enhance the effectiveness, security, and user-friendliness of the PDA solution within a warehouse environment. These standards cover elements such as security, usability, and integration with external systems. The selected non-functional requirements for this solution are:

NFR1: Label Printing (Brother SDK)

The system must integrate seamlessly with the Brother Software Development Kit (SDK), to enable efficient label printing. To ensure that labels are printed precisely and adhered to products for traceability, the printing process should be quick and error-free.

- Requirement Type: Integration.
- Acceptance Criteria: Label printing should be completed within 6 seconds of command execution, with no more than a 1% failure rate.

NFR2: Integration with the Scanning System

The PDA must support reliable and fast scanning of barcodes (both 1D and 2D) to facilitate real-time data capture. The scanning system must work accurately even in low-light conditions and with large barcodes.

- Requirement Type: Usability.
- Acceptance Criteria: The system should maintain a high scanning accuracy rate of 97%.

NFR3: Usability and User Experience

The user interface on the PDA must be intuitive, easy to navigate, and require minimal training for new employees.

- Requirement Type: Usability.
- Acceptance Criteria: It should be possible for users to perform warehouse operations on the PDA without assistance from a coworker.

NFR4: Security

The system must ensure that only authorized users can access and interact with the PDA. Each user must authenticate using their PrestaShop credentials.

- Requirement Type: Security.
- Acceptance Criteria: Access will be checked by examining the user's role and PrestaShop login information. Unauthorized access attempts will be rejected and only users with the 'employee' status will be able to access PDA functions.

5 System Architecture and Design

Since the requirements have been specified, this chapter will focus on a detailed exploration and design of the new warehouse management system. The first part of this chapter is devoted to the system architecture by discussing the main PDA front-end and back-end features as well as their interrelations with other systems and external APIs. The next section of the chapter delves into the database design, explaining the linkages and structure of the data that underpin the system's functionality. Finally, process descriptions address technical implementations and challenges through discussions on them.

5.1 System Architecture

The system architecture of the new warehouse management solution revolves around the PDA back-end, which serves as the central hub for communication between the PDA front end and several critical systems and external APIs. This architecture, including the interaction between these components, is represented in Figure 3, which provides a visual depiction of the system's flow and integration. In this section, we will analyze both the PDA Front-End and PDA Back-End, with detailed references to how they interact within the broader system architecture.

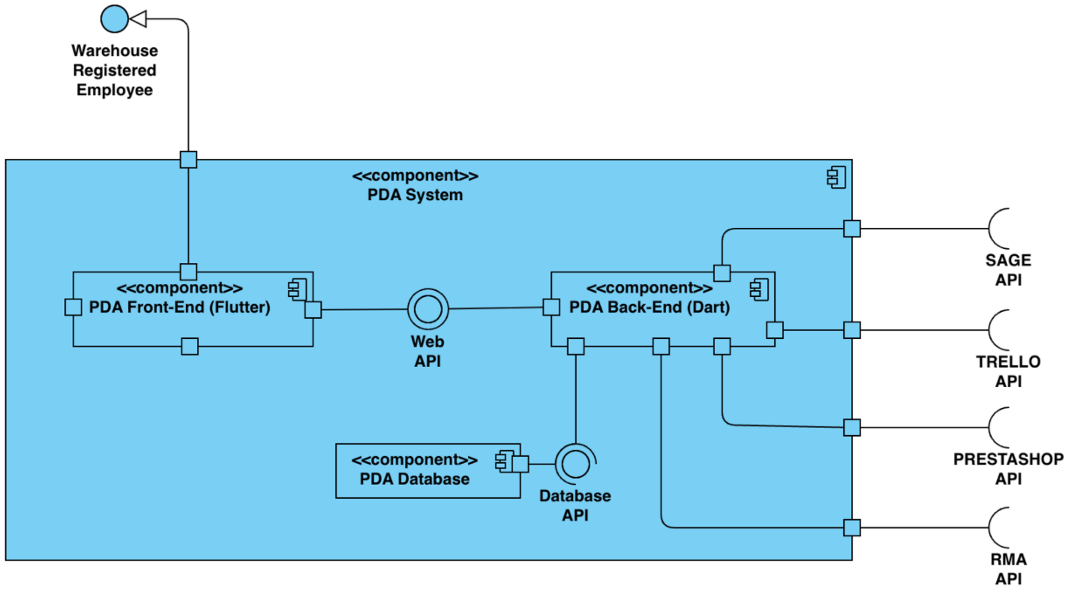

Figure 3 – Logic View Diagram

5.1.1 PDA Front-End

The interaction between warehouse staff and the back-end services is guaranteed by the front-end of the PDA system. Constructed with Flutter, the front-end application connects with various systems to aid in daily warehouse operations.

Key Interactions

1. **Backend PDA Communication**: The front end connects to the PDA backend to enable the real-time exchange of data concerning orders, inventory levels, and warehouse tasks, ensuring system-wide synchronization.

2. **Brother SDK for Label Printing**: The application directly interfaces with the Brother SDK to manage label printing, enabling immediate printing of barcodes and labels without requiring backend intervention.

3. **Built-In Scanner (Mobile SDK)**: The mobile SDK's front-end smoothly integrates the mobile device's built-in scanner to instantly scan barcodes, serial numbers, and QR Codes.

The use of reusable widgets in the front-end application improves efficiency and adaptability for different tasks. The Scan Widget's customizable features include validation logic, display text, and scan type (single or multiple), demonstrating its flexibility. This modular approach allows the user interface to accommodate various tasks, ensuring consistent functionality and a user-friendly experience.

The flexible front-end design makes sure that the application is intuitive and user-friendly, even for new employees. It simplifies complex warehouse processes, providing accessibility while maintaining high operational efficiency.

5.1.2 PDA Back-End

The PDA backend forms the core of Kontrolsat's warehouse management system, responsible for handling communications, data processing, and interactions between various internal systems and external APIs. This system is designed using Dart as the core technology, with a logical separation of the system into entities, routes, services, and utilities, ensuring modularity and maintainability.

Key Interactions

1. **SAGE Database**:

The PDA backend connects to the SAGE database to retrieve and update stock levels, invoice details, customer information, and transactional data.

2. **PDA Database**:

A dedicated PDA database is used to manage the local operations of the warehouse system, including storing temporary information such as product locations, serial numbers, and orders being processed. The database design is analyzed in section 5.2.

3. **PrestaShop**:

PrestaShop interacts with the PDA backend to obtain order details, modify order statuses, and handle out-of-stock notifications. The synchronization between PrestaShop and the PDA backend guarantees that warehouse operations align with real-time customer demand and online sales.

4. **RMA System**:

The PDA backend sends information such as product serial numbers to the RMA system for tracking and verification purposes. This ensures that any incidents related to faulty products can be efficiently managed and traced back to the original shipment.

5. **Trello API**:

The PDA backend communicates with Trello to update task statuses, report issues, and ensure that processes are moving forward efficiently.

Domain Model

The domain model (Figure 4) illustrates how the various objects in the system interact to facilitate key operations. Each class in the diagram represents a significant entity in the system, and their relationships are mapped to demonstrate the flow of data and dependencies between objects.

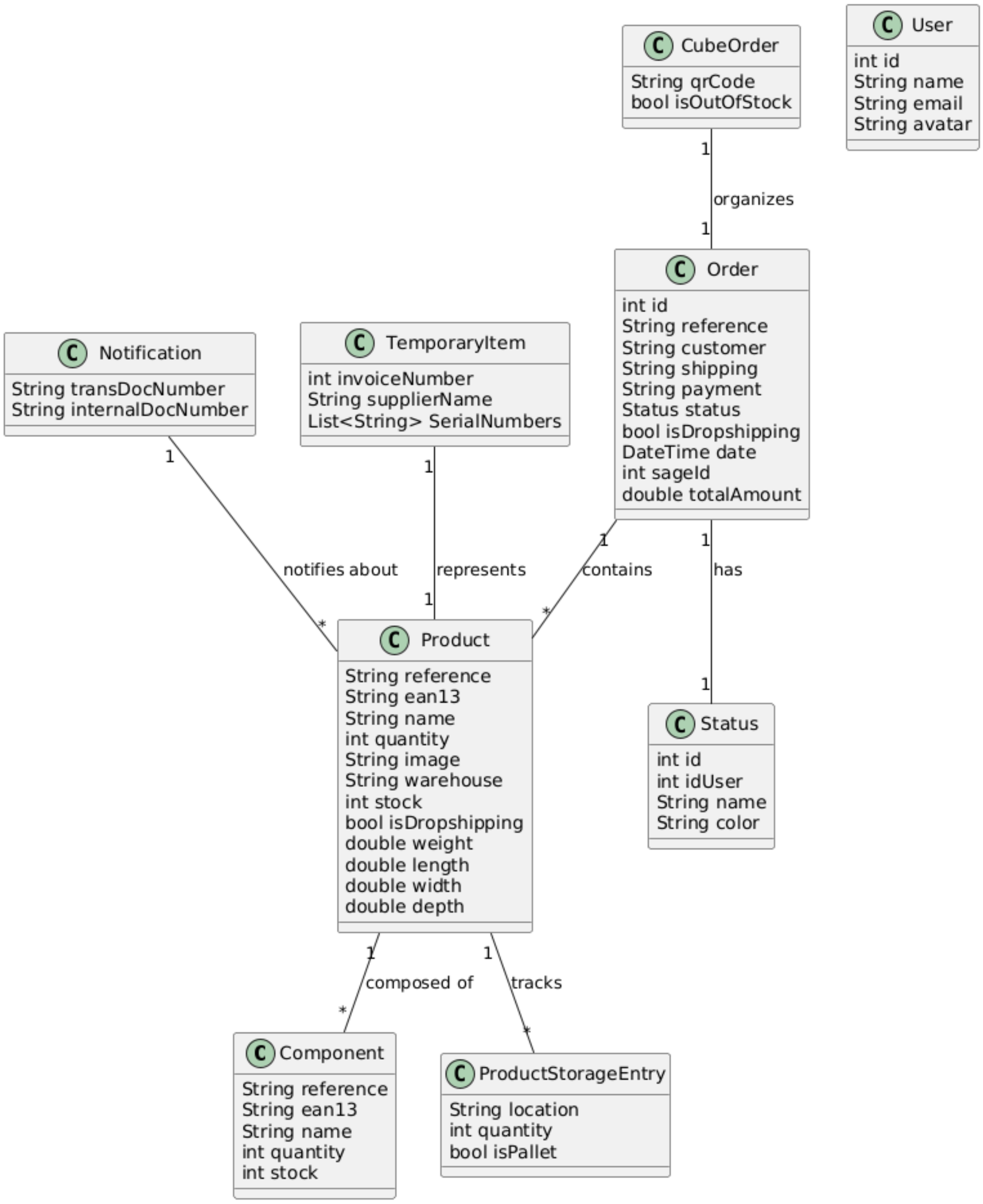

Figure 4 – Domain Model

Key Components:

1. **Order:** Represents customer orders, containing details such as reference, customer information, shipping, products, and payment status. The Order, along with Product, User, and Status, are fetched from PrestaShop, where orders are made on the website.
2. **Product**: Represents individual items in an order. It contains data like European Article Number (EAN13), quantity of the order, warehouse, and physical dimensions. Product details, such as dimensions, are fetched from SAGE.
3. **Component:** Represents parts that make up a product. Like the Product, information about components is fetched from SAGE, such as stock levels.
4. **ProductStorageEntry:** Tracks the storage location of products in the warehouse, including whether the item is on a pallet. These records are managed in the PDA's database.
5. **Status:** Tracks the current state of an order, such as "pending" or "shipped." Status information is managed and updated directly in PrestaShop.
6. **Notification:** Represents notifications for order-related events. Notifications are generated and managed by SAGE to inform users of important actions, such as shipments or stock updates.
7. **TemporaryItem:** Used during the material reception process, it stores temporary product information like serial numbers. This data is stored in the PDA's database.
8. **User:** Represents warehouse staff interacting with the system, responsible for updating order statuses. Although users' actions affect the order flow, the actual status updates occur in PrestaShop. User details are fetched from PrestaShop.
9. **CubeOrder:** Represents orders assigned to cubes in the warehouse, containing the QR Code, and out-of-stock status. It is used for organizing orders within the warehouse and is managed through the PDA database.

Relationships:

- **Order and Product:** An Order contains multiple Product entities, each representing an item that needs to be picked and shipped.
- **Product and Component:** A Product may be composed of multiple Component objects. This relationship is essential for managing complex products that consist of multiple parts.
- **Product and ProductStorageEntry:** Each product can be stored in multiple locations within the warehouse, tracked by the ProductStorageEntry.
- **CubeOrder and Order:** A CubeOrder is associated with a single Order, helping to organize the orders within the warehouse using cubes identified by QR Codes.
- **TemporaryItem and Product:** A TemporaryItem represents a single Product, storing temporary information.

This domain model represents the core business logic that underpins the PDA backend and ensures that the entire system functions cohesively to support Kontrolsat’s operational requirements.

5.2 Database Design

The following database design is structured to support order management, product storage, and warehouse operations. The diagram (Figure 5) illustrates the various entities and their relationships, which ensure effective synchronization with the PDA backend.

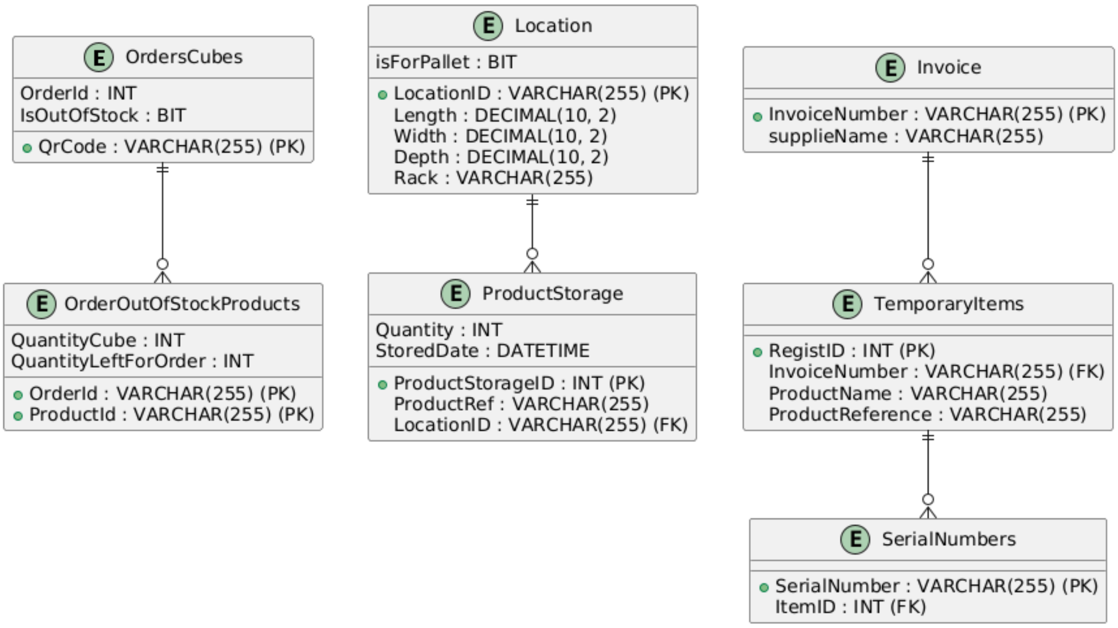

Figure 5 – Data Model

Below is a breakdown of each entity and its purpose within the system:

1. **OrdersCubes**: Sets up orders in the warehouse in cubes to effectively track and handle orders, including dealing with out-of-stock circumstances.
2. **OrderOutOfStockProducts**: Oversees orders that include out-of-stock items, making sure that the items and quantities that are required for order fulfillment are tracked.
3. **Location**: Monitors certain storage areas in the warehouse, taking note of rack positioning and dimensions, and differentiating between pallet and picking storage.
4. **ProductStorage**: Tracks the products and their quantities stored at designated locations.
5. **Invoice**: Tracks supplier invoices for managing the reception of products, linking incoming items to their respective suppliers and invoice details.
6. **TemporaryItems**: Upon receiving products into the warehouse, temporary product data, such as references and serial numbers, is stored until the items are finished processing.
7. **SerialNumbers:** Maintains track of each product's distinct serial number to make product traceability.

Relationships and Design Considerations

- **OrdersCubes and OrderOutOfStockProducts**: The main goal is to track the goods associated with each order that is managed within the out-of-stock cubes.
- **ProductStorage and Location:** They work together to track the whereabouts of every product kept in the warehouse.
- **TemporaryItems and SerialNumbers:** Both entities are linked, to keep track of the unique serial numbers of products temporarily stored before they are fully processed.
- **TemporaryItems and Invoice:** The primary objective of this relationship is to keep track of which invoices the products correspond to during material reception.

5.3 Process Workflow

This section delves into the detailed implementation of key processes developed to enhance warehouse operations at Kontrolsat. Each section covers the specific use cases, workflows, and technical challenges encountered during system development and implementation.

5.3.1 Integration with Scanning System

As a foundational requirement for the advancement of the project, three rugged phones were procured to meet specific operational needs, equipped with built-in scanners capable of reading both 1D and 2D barcodes. The main purpose was to integrate these devices with the mobile SDK, to efficiently capture and process data from each scan performed. This section delves into the technical challenges encountered during the integration process, particularly focusing on permission issues related to Security-Enhanced Linux (SELinux) and the subsequent solutions that were explored to mitigate these challenges.

Device Integration and Initial Challenges

The rugged phones selected for this project were chosen not only for their durability but also because of the exceptional quality of their built-in scanners. These scanners are fast and precise, crucial features for high-efficiency environments like our warehouse operations. Additionally, the scanners do not significantly add to the size of the devices, allowing them to maintain the form factor of a normal phone. Each device comes with a strong, non-removable cover integrated into the phone, providing essential protection in the rigorous conditions of a warehouse setting.

The initial task involved compiling the necessary .jar and .aar files and integrating them into the Android portion of our project. This was crucial to enable UART communication with the device's system. UART (Universal Asynchronous Receiver-Transmitter) communication is a serial protocol used in embedded systems for interfacing microcontrollers with other hardware or computers. It is essential for direct, low-level interactions with hardware components. For the purposes project, the UART communication needed to interface directly with the device's ttyS1 file, a representative of the serial port within the Android system. The tty files in Unix-like systems like Android are device files that represent a terminal device (one of the simplest forms of device files in Unix). They handle input and output operations of text and data, where ttyS1 typically represents a serial port, often used for direct hardware control and communication tasks. This specific file was necessary to establish a robust link between the application software and the hardware scanner, leveraging UART's capabilities to transmit the scanned data efficiently and reliably.

Root Access Attempts and Implications

To overcome the SELinux restrictions, it was attempted to root the rugged phones to modify their operating system configurations. Rooting these devices proved to be particularly challenging due to the MediaTek chipset they were equipped with. Traditional tools like KingoRoot, which are often effective for a wide range of devices, were unsuccessful due to the specific security implementations and architectural choices in the MediaTek design.

The development team responsible for the devices was contacted for assistance in achieving root access. A request was made for access to the base ROM originally installed on the phones, to modify it to gain root privileges. Despite the development team providing alternative versions of Android to facilitate this process, all attempts to root the device using these modified systems failed to yield the desired result.

Temporary Solution Using ADB

As rooting the devices directly proved unfeasible, the Android Debug Bridge (ADB) was used as a temporary workaround. By using the commands "*adb root*" and "*adb shell setenforce 0*", SELinux was set to permissive mode temporarily. This adjustment allowed the application to perform the scanning operations by bypassing the SELinux policies that were initially blocking access to the necessary hardware.

- "***adb root"*****:** This command restarts the ADB daemon with root permissions, allowing high-level access to the device's system files from a connected computer;
- "***adb shell setenforce 0"*****:** This command changes SELinux to permissive mode, reducing the restrictions enforced by SELinux and enabling the application to interact with the hardware required for scanning.

This approach, while effective in overcoming the immediate challenges, was not a permanent solution. The use of ADB requires either a physical connection to a computer or a network setup that supports wireless ADB, which is not feasible for deployment in typical field operations. Additionally, the permissions reset upon device reboot, necessitating a manual reapplication of the commands after each restart.

5.3.2 Material Reception and Product Storage

This section explores the detailed processes involved in the reception and storage of materials, vital elements of warehouse management. It outlines a systematic approach that spans from the initial reception of goods to their final storage. This process is divided into three key stages, each highlighting the integration of technology.

1. **Initial Reception and Data Capture**

All processes that involve direct interaction with the system always begin with the log-in step. The reception process begins by identifying the supplier, using data integrated from SAGE.

Product Identification and Registration

Products are identified by initiating a new group of product addition processes, starting with the scanning of the EAN13 barcode. Following the barcode scan, multiple serial numbers are scanned. If a serial number is repeated, or an EAN13 that has already been identified is scanned, an error notification is displayed, alerting to the incorrect scan. All data from these interactions are temporarily stored in the PDA database, pending permanent storage in the SAGE database.

Documentation and TRELLO Integration

Following product identification, an internal ID is generated for data synchronization. A photo of the products and invoice information, such as payment status, is uploaded through the PDA, which communicates with the TRELLO API to ensure all details are accurately captured and managed effectively.

2. **Data Verification and Update**

Office employees begin processing the received product data and entering additional details into the billing system.

Data Synchronization

Essential information, including serial numbers and EAN13 codes, is definitively saved in SAGE and RMA at this stage. The necessity to link the internal ID from the temporary database to the permanent records in SAGE and the RMA database ensures accuracy and traceability.

3. **Storage and Synchronization**

Employees receive notifications on their PDAs to store the processed products from the invoice in their respective locations.

Dimension Verification

If any product lacks weight or dimensional data, the system prompts for this information to be added. This data is crucial for other processes and future features. For example, both weight and dimensional data are used to select the appropriate carrier. To utilize this data effectively, it was integrated into SEGA, the software responsible for generating transport guides. The importance of weight information necessitated its immediate availability.

Product Storage

Employees proceed to the designated storage location, scanning the QR Code of the respective location. This information, along with the quantities in each location, is recorded in the PDA database that manages stock locations and quantities. After storing every product in each location, the process can be concluded.

Order Fulfillment

If there is an existing order waiting for a specific product, the system directs employees to place it in the designated cube marked with a QR Code. This cube system, particularly used for orders containing out-of-stock products, enhances efficiency in order fulfillment. A detailed discussion of this cube process will be provided in section 5.3.5.

Data Synchronization Across Platforms

The use of PDAs ensures that all data, including EAN13 codes, supplier details, and serial numbers which previously could vary across RMA, SAGE, and the website, are now synchronized. This uniformity is maintained across all platforms, ensuring data integrity and consistency.

5.3.3 Label Printing via Brother SDK

When storing products, if an item lacks an EAN13 barcode, it can be generated or updated, triggering the label printing process. This process involves printing a barcode with the new EAN13 onto a predefined template created using the P-Touch app, which is essential for managing inventory accuracy and traceability within the warehouse.

The system interfaces with the selected Brother printer, specifying which predefined template to use for each print job via a template key, ensuring every label accurately reflects the product information.

In conclusion, following successful communication, labels are produced and applied to the corresponding products, ensuring that all items are labeled correctly. This integration allows for the newly generated EAN13 to be synchronized across all platforms.

5.3.4 Picking Process

Once logged in, the system retrieves all orders that need to be prepared. Employees can then claim these orders, assigning them to their accounts, which automatically updates the order status in PrestaShop, where all statuses are managed. Only orders that are marked as 'payment completed,' free of stock issues, and not linked to dropshipping are available for claiming. Orders can be claimed based on their section or type, such as those on the ground floor, or first floor, orders that consist of kits with multiple components, and those marked as late. It is important to note that large domestic items cannot be claimed as they follow a separate process, which will be explained in section 5.3.8.

Reassignment and Release of Orders

Employees can also reassign claimed orders to another user if needed, such as if they must visit the physical store or address any other issue. Alternatively, they can release the orders, making them available for other employees to claim again.

Order Shortage Display

It is possible to view all the products from orders that are out of stock, as identified by the actual stock levels in SAGE.

Claiming Process

To claim an order, the backend process first confirms the available cubes in the PDA database and limits the number of orders to the number of available cubes. Products are grouped across different orders to prevent picking the same product multiple times for different orders. The limit for claiming is set to either 12 orders or 30 products total. A selection is also made using a REGEX to prioritize orders that are in the same aisles and closest together. For instance, if products in the first order are located at A1, and there's a choice between orders at locations A4 and B4, the pair of orders at locations A1 and A4 will be selected. This entire process applies to both orders on the ground floor and those on the first floor, as well as orders involving kits.

Picking Process

Once all orders are claimed, the system displays the products to be picked. QR Codes are affixed to shelves at their respective locations, enabling scanning for location verification. The employee proceeds to each location, scans the QR Code to confirm the location, and continues by scanning the number of products needed (with the scanned EAN13 matching the system record) before placing them in a physical cart to collect the products. The system tracks each completed product scan, and the process repeats until all products have been successfully collected.

Product Distribution Using Cubes

After all products are collected, they need to be distributed through their orders using the cubes, a process that will be detailed further in section 5.3.5, as previously noted.

Stock Management and Replenishment

Although stock management and replenishment are integral to the picking process, this is a complex process that will be detailed extensively in section 5.3.6.

5.3.5 Order Organization and Cube Allocation

After the picking is completed, the products are initially mixed. To distribute these products among their respective orders, two shelves have been constructed, each with 16 cubes measuring 50 cm in height, 45 cm in width, and 50 cm in depth. Each cube on these shelves contains a QR Code for identification. Once orders are claimed by a user, it is verified which cubes are not yet associated with an order in the PDA database, and each order is then assigned to a specific cube, meaning each cube corresponds to a particular order.

Consequently, once the cart is filled with products from the picking process, the employee scans the EAN13 barcode of the product they select first from the cart. The software automatically prompts the employee to scan the QR Code of the cube corresponding to that product's order, guiding the placement of the product in the designated cube.

Mobile Carts and Billing

The cart is mobile and can subsequently be moved to the billing stations. The billing process is conducted on SEGA, at a station equipped with a computer, where the cube of the order is identified, items are re-checked, and packaged, and a transport guide relative to the order is generated and affixed. This ensures the order is ready to be handed over to the carrier.

Special Cases for Large or Irregular Items

Although there is already a separation between small and medium products in this warehouse and the second warehouse that contains large products, some items still do not fit within the dimensions of the cubes. Such products, identified by the system, are placed in a specific area near the billing location, and the order number they belong to is manually assigned. This process depends on human intervention and was not integrated into the PDA, as it is a rare occurrence, and no issues have been detected in order separation for these products.

5.3.6 Stock Management and Replenishment

One of the requirements for the new PDA was to know the exact location of each product, not just the total stock levels. The PDA database stores all locations and the respective quantities at each of these locations. This led to a division between picking locations and pallet locations. Picking locations are where products are already unboxed and easily accessible, typically placed on the lower shelves. These locations are used to indicate to the employee where the product is located and are utilized during the picking process, as previously mentioned. Additionally, pallet locations were added, where products are stored in boxed form on pallets. Each product has one picking location, but there can be multiple pallet locations where these are stored.

Replenishing Stock

During the picking process, when the stock at a picking location drops to zero, it is necessary to go to the pallet locations, retrieve the products, and place them in their respective picking locations. Information about pallet locations is displayed to help identify which pallet needs to be accessed. The employee scans the pallet, and depending on the scenario, if no information about that pallet is available in the PDA database, it is necessary to enter the number of products on the pallet, followed by the quantity to be moved to the picking location. If the pallet already contains information about the product, only the quantity transferred to the picking location needs to be recorded. Having this information readily available is advantageous, as it prevents employees from having to search for products and lower multiple pallets to find the desired item. All data is synchronized with the PDA database.

Automatic Replenishing Stock

If the software detects that the quantity of products at a picking location is zero, it automatically initiates the stock replenishment process. However, this information might be incorrect, and in such cases, the actual quantity found at that location is requested and updated. Again, all data is synchronized with the PDA database.

Correct Stock

If the software does not automatically trigger a stock replenishment action when the stock at a picking location reaches zero due to data discrepancies, it becomes necessary to correct the stock. The process follows a similar procedure to the stock replenishment process, with one key difference: it disregards the erroneous data regarding the quantity at the picking location, and the quantity of products replenished from the pallets is updated as the new quantity present at the picking location.

Location Update

Each time the location of a product is verified, it is possible to update its picking location by scanning the new one.

5.3.7 Out Of Stock Management

During the picking process, if SAGE indicates a certain stock level for a product that is not physically present in the warehouse, it is necessary to report the quantity that is out of stock and update the status of the respective orders. This enables reporting stock shortages during any product’s picking process. Orders selected based on out-of-stock products are updated in their status on PRESTASHOP.

Detailed Out-of-Stock Scenario

For instance, if three units of a product are needed, the shortage can be reported as total, where none of the three required products are available, and in this case, all orders will be updated to reflect the out-of-stock status. Alternatively, if only one of the three products is available, only two products are reported as out of stock. In this scenario, it is necessary to choose which order will have its status updated to out-of-stock.

Analyzing this example, suppose order ID 1 requires two units of Product A, followed by order ID 2 which needs one unit, and order ID 3 also requires one unit. If the number reported as out of stock is two, only order 1 will update its status to out of stock, but if the number reported is three, then at least two orders must have their status updated. Choosing between orders ID 2 or 3 involves a scoring system where the highest score is assigned to an order that has been waiting the least amount of time or has a lower monetary value.

Orders with the highest scores are prioritized for out-of-stock updates (ensuring that those with longer wait times and higher values are dispatched first), while orders with the lowest scores are prioritized to receive the product. There is a limit: if an order has been waiting for more than four days, it will always be the order with the lowest score that is prioritized for dispatch. To conclude, when an out-of-stock situation is reported, the number of products remaining to be scanned is the number reported as out of stock, which is then used to select which orders are marked as out of stock.

Once the order status is updated to 'out-of-stock' in PrestaShop, the list of all out-of-stock products becomes accessible both through the PDA and in the PrestaShop back office.

Handling Partially Fulfilled Orders

During the picking process, when an order is reported as out of stock, the remaining products of the order may or may not have already been picked. Instead of placing the remaining items back into their respective locations after updating the order to out-of-stock, the process continues normally, and the remaining products of the order are collected.

To facilitate the management of orders lacking stock, four out-of-stock cubes have been positioned in a specific and fixed area within the warehouse. An order previously associated with a cube on the shelf is now updated and linked to one of these four out-of-stock cubes. Thus, when products are sorted into their designated cubes on the shelf, scanning a product from an out-of-stock order prompts the scan of the corresponding out-of-stock cube, and the item is then placed in that cube. If these four cubes become filled, a new location for this order can be added.

As material is received, it can be automatically directed to these cube areas instead of being stored elsewhere in the warehouse. Moreover, these out-of-stock cubes are strategically located in a place where all employees frequently pass, reinforcing the need to address these orders swiftly, whether by receiving the missing material or by substituting a new one after the customer's final consent.

5.3.8 Large Domestic Product Dispatch

As previously mentioned, a separate process is necessary for dispatching large domestic products due to their storage in a different warehouse approximately 500 meters from the main warehouse.

Verification and Dispatch Process

Initially, the worker proceeds to scan the invoice. The invoice number obtained from this scan is then used to display the large domestic products listed on that invoice.

The verification process starts with scanning the product's EAN13 barcode for confirmation, followed by its serial number. Once all items on the invoice have been verified, the next step is to scan the tracking number. It's important to note that multiple tracking numbers can be selected, as each large domestic item may have its own independent shipping route.

Once verified, the serial numbers are sent to the RMA and SAGE systems. The tracking number is relayed to PrestaShop.

Handling Barcodes on Large Items

A rescan of serial numbers is available if needed, as the barcode's large size can occasionally cause the scanner to struggle with capturing the correct and complete value.

Final Steps and Data Registration

Once the process is completed, the employee who conducted the operation and the time is recorded and sent to PrestaShop.

5.3.9 Product's Information

The final process in the system allows users to search for and view detailed product information, ensuring warehouse employees have easy access to stock levels and product data. Items can be searched by name, EAN13, or reference, with matching products displayed, along with key product details. This information is sourced from both SAGE and the website. After selecting a product, all relevant details are shown, including the quantity in each location, as well as attributes such as height, weight, and length. Additionally, the product's dimensions can be updated directly within the system.

Designed for Early Use and Confusion Prevention

To mitigate confusion, particularly when adapting to the new PDA and its recently implemented procedures. In instances of uncertainty, users can search for a specific order by its reference. This search displays all products associated with the order, along with additional details such as the address and order status.

6 Implementation

Now that everything is properly analyzed, it is time to provide an in-depth examination of how the processes described in previous chapters were implemented within the system. Each section references specific figures to demonstrate the practical application of these processes, providing a visual aid to understanding the system's functionality.

6.1 Scanning System

In the context of the integration with the scanning system process, as outlined in section 5.3.1, the code initiates by setting up the NLDevice for UART communication specific to device class UART. It then registers a broadcast receiver to actively listen for USB device connections and disconnections, ensuring the system remains responsive to changes in hardware status. Attempting to open a UART connection on /dev/ttyS1 with a baud rate of 115200, establishes a listener that handles incoming byte streams, converting them into string data for further processing. If the connection fails, an error is logged, indicating potential issues that require attention. Concurrently, the system subscribes to a data publisher that operates on the Android main thread, allowing for real-time data processing and user interface updates. This setup highlights the seamless integration of hardware control and data handling within the app, ensuring optimal performance and reliability. The code and its functionalities are clearly outlined in the Kotlin file within the Android section of the Flutter app, as depicted in Figure 6. In addition, a specialized widget was integrated into the Flutter app, designed to initiate scanning operations whenever required. This widget interacts seamlessly with the Kotlin code, accepting numerous parameters such as the validation function for each scan, customizable display text, and options for single or multiple value entries.

```
private fun initializeScannerRuggedTablet() {
        ds = NLDevice(NLDeviceStream.DevClass.DEV_UART)

        // Register a broadcast receiver to listen to USB attach and detach events
        val filter = IntentFilter().apply { this: IntentFilter
            addAction(UsbManager.ACTION_USB_DEVICE_ATTACHED)
            addAction(UsbManager.ACTION_USB_DEVICE_DETACHED)
        }
        registerReceiver(usbReceiver, filter)

        // Attempt to open UART
         val uartSuccess = ds?.open("/dev/ttyS1", 115200, object : NLDeviceStream.NLUartListener {
            override fun actionRecv(recvBuff: ByteArray, len: Int) {

                val scannedData = String(recvBuff,  offset: 0, len)
                scannerDataPublisher.onNext(scannedData)
            }
        }) ?: false

        if (!uartSuccess) {
            Log.e( tag: "MainActivity",  msg: "Failed to open UART device")
        }
        // Subscribe to the data publisher
        scannerDataPublisher
            .observeOn(AndroidSchedulers.mainThread())
            .subscribe(this::sendDataToFlutter, this::handleError)
}
```

Figure 6 – Code Integration

Figure 7 and Figure 8 show the phone scanning a barcode.

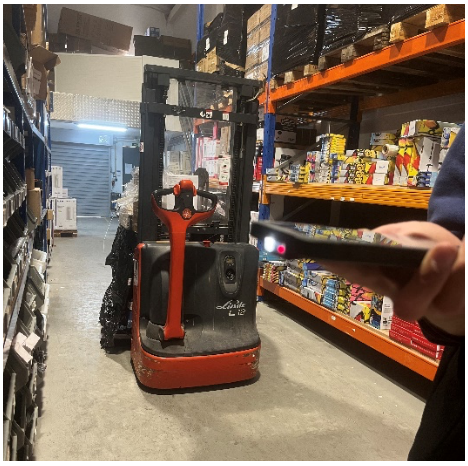

Figure 7 – Phone

Figure 8 – Location

6.2 Material Reception and Product Storage

This process, as outlined in section 5.3.2, begins with the log-in step, which is always the first action on the PDA, as shown in Figure 9. To select the supplier, a searchable dropdown list is displayed, allowing users to easily search and narrow down the options from many suppliers (Figure 10).

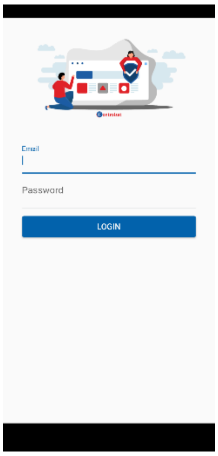

Figure 9 – Login Screen

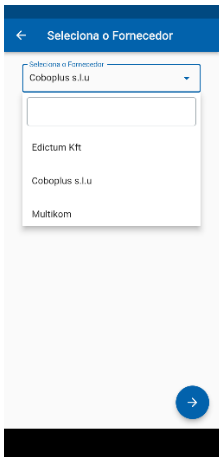

Figure 10 – Select supplier

After clicking on the blue button in the bottom left-hand corner, the widget for scanning the EAN13 is displayed, which shows a button in case the product's EAN13 is not found (Figure 11). When scanning serial numbers, it is also possible to click a button if the product does not contain a serial number, and the total number of serial numbers registered is displayed in the top left-hand corner (Figure 12). When the user is ready to complete the serial number scanning process, they can press the button located in the top right corner (Figure 13). If the scan is incorrect, the widget displays an error message along with the scanned serial number, allowing the user to easily identify and understand the issue (Figure 14). Once the card is created with the identified products (Figure 15), the user can click a red button to delete the card (Figure 16 and Figure 17).

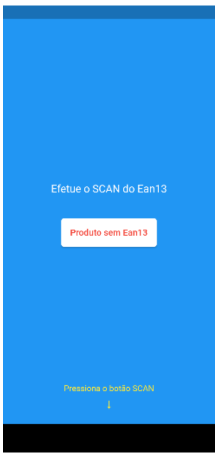

Figure 11 – Scan EAN13

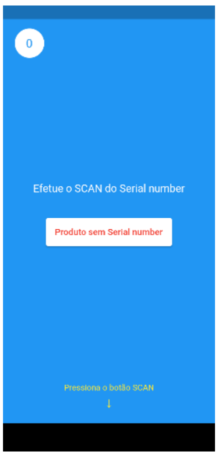

Figure 12 – Scan Serial Numbers

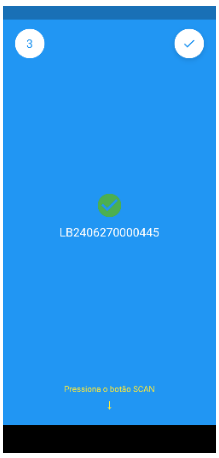

Figure 13 – Success serial numbers scan

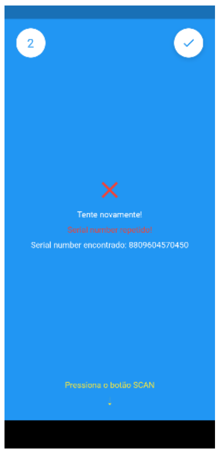

Figure 14 – Wrong Serial Number Scan

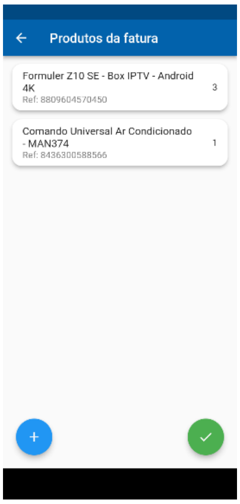

Figure 15 – Main menu with items added

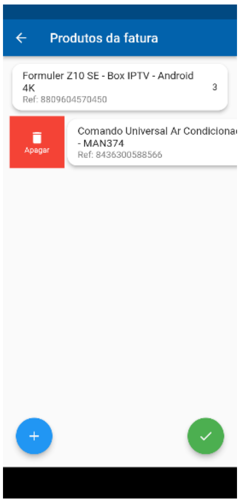

Figure 16 – Possibility items to delete

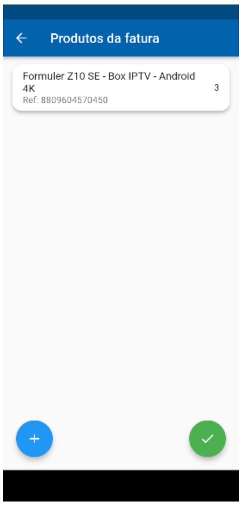

Figure 17 – Result of the deletion

The internal ID generated is displayed in a pop-up with a message prompting the user to write the ID on the invoice, serving as a second verification (Figure 18). Tags are shown in selectable boxes, allowing multiple tags to be chosen (Figure 19). If the user wishes to create a new card, two text boxes are provided to enter the desired title and description (Figure 21). For updating an existing title, a dropdown list of available cards to update is displayed (Figure 20).

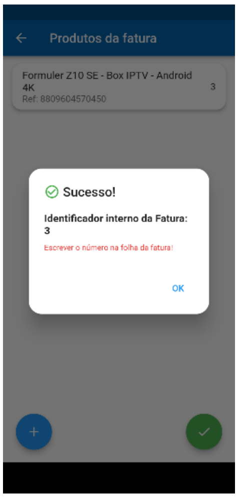

Figure 18 – Internal ID Generation

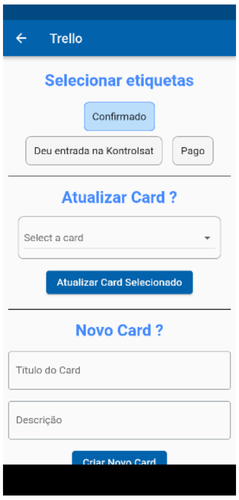

Figure 19 – Menu to communicate with TRELLO

Figure 20 – Update a card in TRELLO

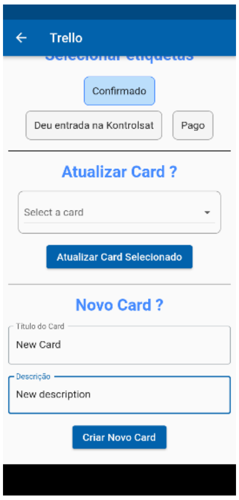

Figure 21 – New card TRELLO

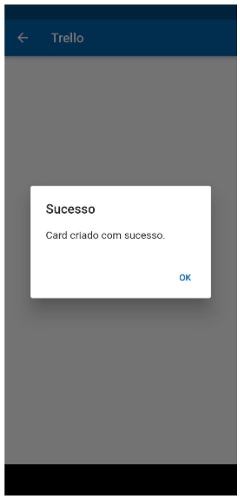

Figure 22 – Card created

Finally, a pop-up appears to confirm that the process has been concluded (Figure 22). The TRELLO board is shown in Figure 23, along with the creation of a card in Figure 24 and Figure 25.

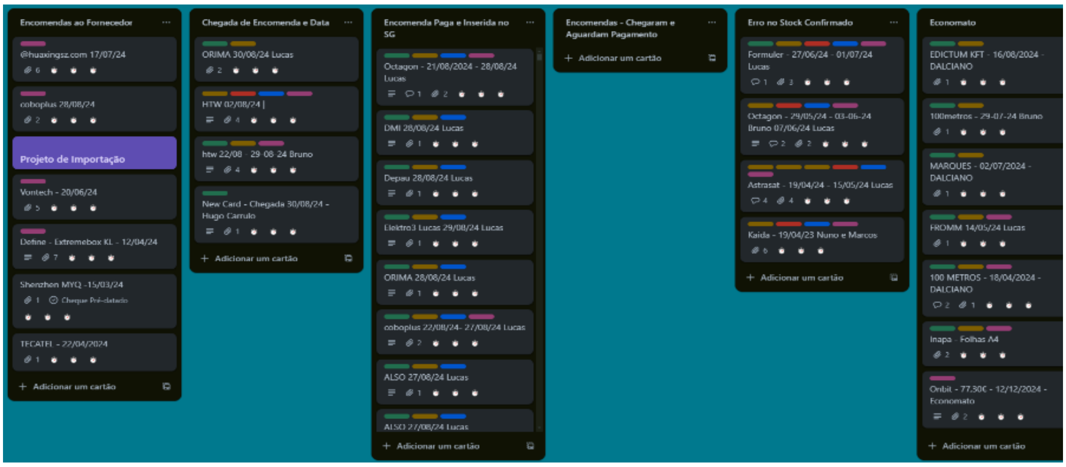

Figure 23 – TRELLO board

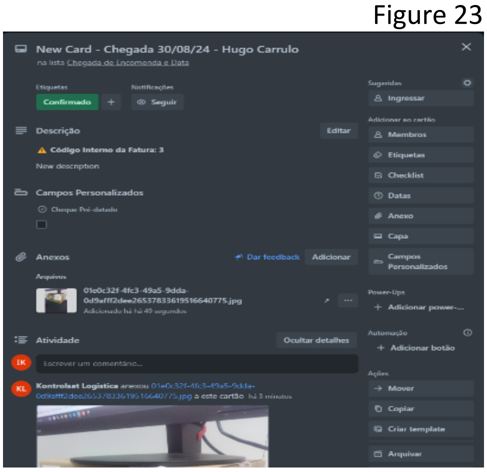

Figure 24 – TRELLO New Card

Figure 25 – TRELLO New Card Photo

In the Storage and Synchronization process, a notification icon displaying the number of notifications is shown (Figure 26). After selecting an invoice, each product on the invoice is displayed on a card (Figure 27). Clicking on a product brings up the screen for scanning its EAN13 barcode (Figure 28).

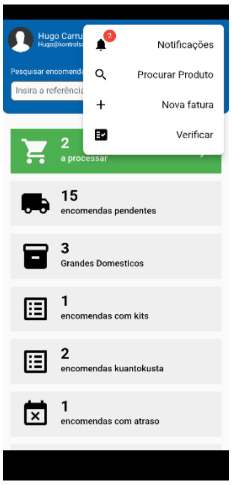

Figure 26 – Dropdown Menu on the initial screen

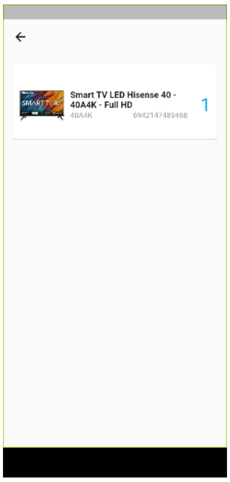

Figure 27 – Invoice Product List

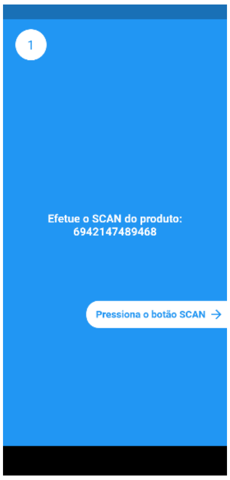

Figure 28 – Scan of the intended EAN13

To update the product's information, the screen in Figure 29 appears, showing the product's current data, which can be updated by editing the text fields.

The screen for scanning the desired storage location to store the product is displayed again (Figure 30). The card design is updated with a checkbox, and once all the cards have this checkbox, a green button appears in the bottom right-hand corner to complete the process (Figure 31).

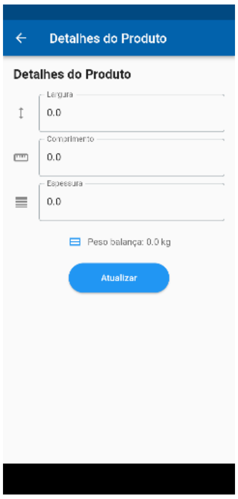

Figure 29 – Add details of the product

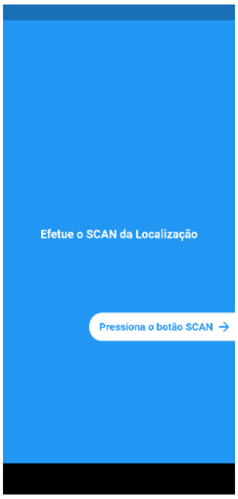

Figure 30 – Scan of the location

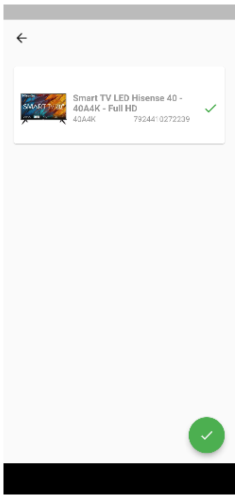

Figure 31 – Finished Process

6.3 Label Printing via Brother SDK

To initiate the label printing process, as detailed in section 5.3.3, users are presented with two options as shown in Figure 32, a red button to generate a unique internal EAN13, or a green button to update the value based on the input text. The desired number of labels to be printed is then entered, as illustrated in Figure 33.

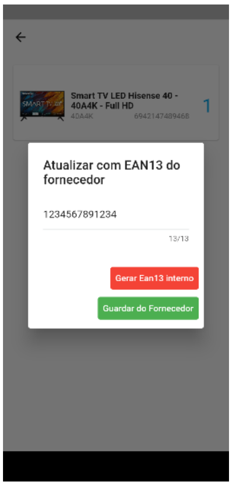

Figure 32 – Options to generate or update EAN13 barcode

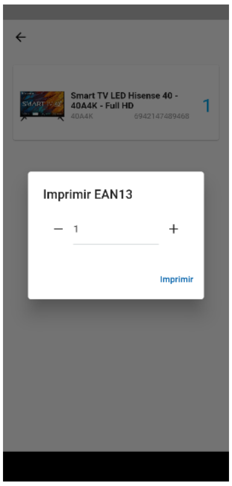

Figure 33 – Specify the number of labels to print

This procedure is managed through a function in the Kotlin file, outlined in Figure 34.

```
private fun printTemplate(printerIP: String?, templateKey: Int, quantity: Int, fields: List<Map<String, String>>, encode: TemplateObjectReplacer.Encode) {
    try {
        val channel = Channel.newWifiChannel(printerIP)
        val generateResult = PrinterDriverGenerator.openChannel(channel)
        if (generateResult.error.code != OpenChannelError.ErrorCode.NoError) {
            throw Exception("Error opening channel: ${generateResult.error.code}")
        }

        val printerDriver = generateResult.driver
        val ptSettings = PTTemplatePrintSettings(PrinterModel.TD_2120N)
        ptSettings.numCopies = quantity
        val replacers = ArrayList<TemplateObjectReplacer>()

        for(field in fields) {
            replacers.add(TemplateObjectReplacer( name: field["name"] ?: "",  value: field["newText"] ?: "", encode))
        }

        val printError = printerDriver.printTemplate(templateKey, ptSettings, replacers)
        if (printError.code != PrintError.ErrorCode.NoError) {
            throw Exception("Print error: ${printError.code}")
        }

        printerDriver.closeChannel()
    } catch (e: Exception) {
        Log.e( tag: "App",  msg: "Exception in printTemplate: ${e.message}", e)
        throw e  // Optionally re-throw to handle it further up if necessary
    }
}
```

Figure 34 – Code to print

The *printTemplate* function is pivotal for initiating label printing and includes several parameters:

- *printerIP*: the IP address of the printer, used to establish a Wi-Fi channel;
- *templateKey*: an integer representing the template to be used;
- *quantity*: the number of copies to print;
- *fields*: a list of maps where each map contains data for one label, such as the product name or EAN13 code;
- *encode*: specifies the encoding method for text replacement in the template.

The printing process starts by creating a new Wi-Fi channel using the *printerIP*. The *PrinterDriverGenerator.openChannel* method tries to open a communication channel, throwing an error if it fails. Once the channel is successfully opened, the printer driver is retrieved, and print settings are configured. The *PTTemplatePrintSettings* method specifies the printer model and sets the number of copies to be printed. The *TemplateObjectReplacer* class creates replacers to substitute placeholders in the template with actual data from the field's parameter. Each field in the template has an ID and a corresponding value, ensuring that labels printed accurately reflect the product information. The *printerDriver.printTemplate* method then executes the print job. Finally, the printer driver closes the communication channel to maintain system stability and ensure efficient resource management. In conclusion, following successful communication, labels are produced as illustrated in Figure 35 and Figure 36.

Figure 35 – Brother Printer

Figure 36 – Label printed

6.4 Picking Process

Going back to the process described in section 5.3.4, once employees log in, they are presented with a screen displaying various cards that represent different categories of orders to be claimed (Figure 37). Each card corresponds to a specific type of operation or order status within the warehouse.

- The first card shows orders that have already been claimed by the employee. If the employee doesn't have any claimed orders, this card allows them to claim orders from the ground floor of the warehouse.
- The second card shows orders available to be claimed from the first floor.
- The third card displays large domestic items, which cannot be claimed but are available for viewing.
- The fourth card allows employees to claim orders that consist of kits with multiple components.
- The fifth card enables employees to claim orders marked as late.
- Additional cards display orders that have already been claimed by other employees and show a list of out-of-stock products.

After selecting a card to claim orders, the system assigns the orders to the employee's account, and all grouped products are displayed on cards with detailed information, such as product photo, name, reference, EAN13, location, and the number of products to be picked (Figure 38).

Figure 37 – Initial menu with all cards

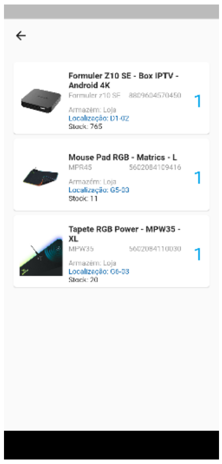

Figure 38 – Products to be picked

By clicking on each card, the system displays the screen for scanning the respective location and EAN13 of the product, as seen in Figure 39 and Figure 41. The successful scans are shown in Figure 40 and Figure 42, respectively. After each product scan, the corresponding card is updated with a checkmark, as seen in Figure 43. This process is repeated until all cards show a checkmark, indicating that the products have been collected. A green button then appears to conclude the process, which is depicted in Figure 44.

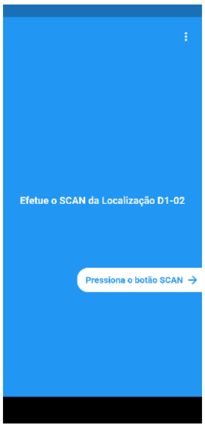

Figure 39 – Location Scan

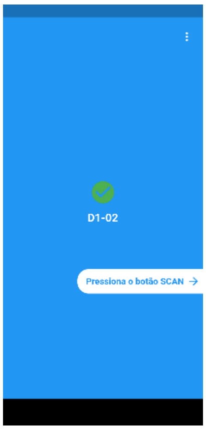

Figure 40 – Successful Scan

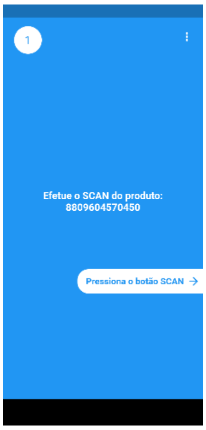

Figure 41 – EAN13 Scan

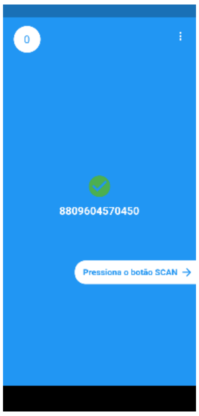

Figure 42 – Successful Scan

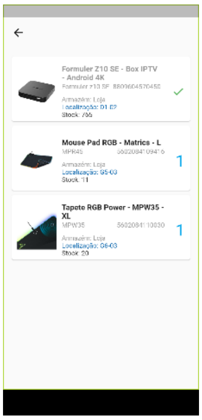

Figure 43 – Card updated with a checkmark

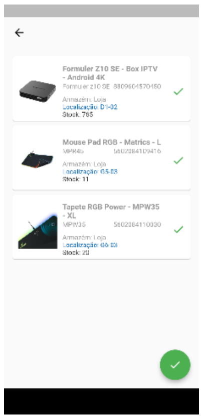

Figure 44 – Products all picked and process finished

6.5 Order Organization and Cube Allocation

As described in the process in section 5.3.5 of organizing orders into their cubes, the screen for scanning the product is shown in Figure 45, followed by the screen for scanning the corresponding cube (Figure 46 and Figure 47).

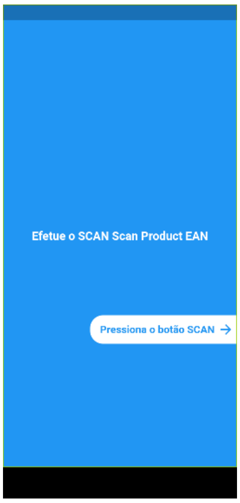

Figure 45 – Scan of the product to put in the cube

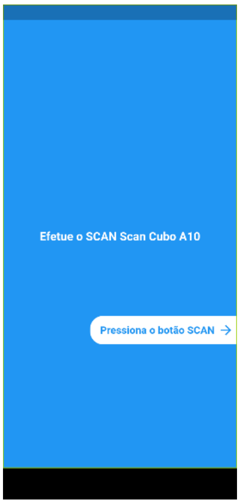

Figure 46 – Scan of the corresponding cube

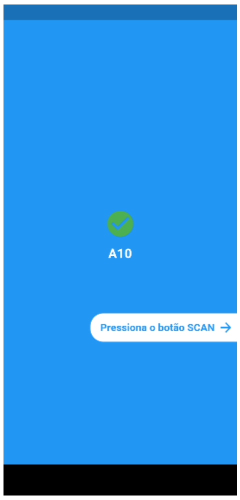

Figure 47 – Successful scan of the cube

6.6 Stock Management and Replenishment

As outlined in section 5.3.6, there are four key implementations related to stock management and replenishment.

6.6.1 Replenishing Stock

During the picking process, if stock needs to be replenished, the employee selects the option to do so, as shown in Figure 48. This displays a table with the pallet locations (Figure 49). After the pallet is scanned (Figure 50), a pop-up prompts the employee to enter all the necessary information about the quantities on the pallet and the quantities to be transferred to the picking location (Figure 51 and Figure 52).

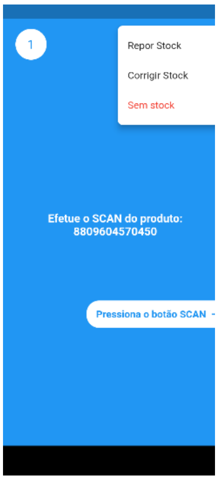

Figure 48 – Dropdown menu picking

Figure 49 – Pallet's stock information

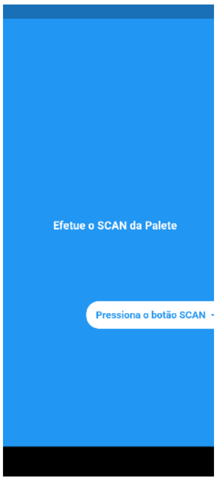

Figure 50 – Pallet scan

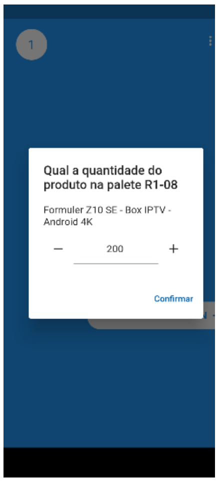

Figure 51 – Quantity present on the pallet

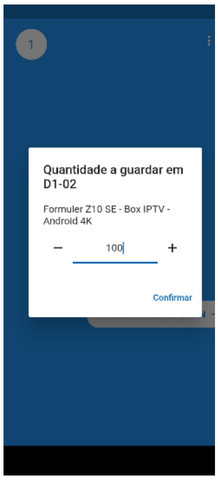

Figure 52 – Quantity to be transferred to the picking location

6.6.2 Automatic Replenishing Stock

When the software automatically initiates the stock replenishment process, the information can be corrected by clicking a red button to report discrepancies, as seen in Figure 53.

Figure 53 – Replenishment stock identified by the software

6.6.3 Correct Stock

To correct stock levels, an option can be selected from the Dropdown Menu to begin the correction process, as shown in Figure 48.

6.6.4 Location Update

To update the location, this action is triggered by the button located at the top right of the screen, as shown in Figure 54.

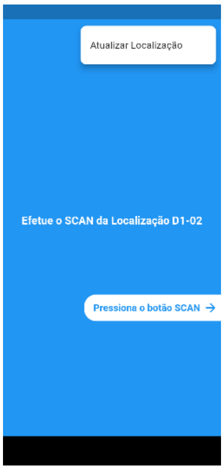

Figure 54 – Location Update

6.7 Out-of-Stock Management

Building on the process explained in section 5.3.7, the implementation allows employees to mark a product as out of stock during the picking process by clicking the 'Out of Stock' button, which subsequently updates the order status. This action is in Figure 55.

As described in the out-of-stock process, orders are selected based on their calculated scores. The function (Figure 57) responsible for calculating the score evaluates each order's urgency and value. It first calculates how many days have passed since the order was placed using the daysDifference. If the order surpasses the urgent threshold, a score is assigned based on the number of days it has been delayed. Additionally, for orders with a value of 50 euros or more, an extra day is added to the score, where every 50 euros contributes an additional day of urgency. This system ensures that orders are prioritized and processed based on both the time they've waited and their monetary value. Once an order is flagged as out-of-stock, it is possible to view the list of all out-of-stock products after selecting the respective card in the initial menu, as shown in Figure 56.

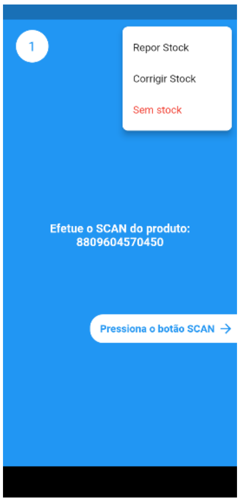

Figure 55 – Menu to out-of-stock

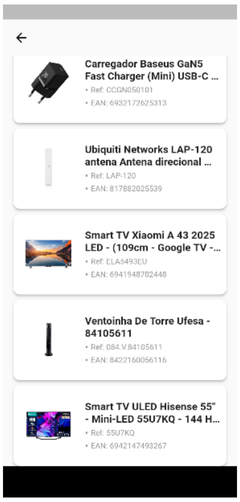

Figure 56 – Out-of-stock products list

```
double calculateRelativeOrderScore(Order order, List<Order> allOrders, DateTime now,
                                   int timeThresholdDays, int urgentThresholdDays, double priceThreshold) {
  double score = 0.0;
  int daysSinceOrder = now.difference(order.date).inDays;
  double orderPayment = order.totalAmount ?? 0.0;

  // Basic time-based scoring
  if (daysSinceOrder > urgentThresholdDays) {
    score += 1000;  // Significantly overdue orders get a high bonus
  } else {
    score += (daysSinceOrder / timeThresholdDays) * 100;  // Proportional to time waited
  }

  // Price-based scoring, equating monetary value to additional waiting days
  for (Order other in allOrders) {
    if (other.id != order.id) {
      double otherPayment = other.totalAmount ?? 0.0;
      double priceDifference = orderPayment - otherPayment;
      if (priceDifference > 0) {
        // Normalize price difference so that every $50 over is like an extra day
        score += (priceDifference / priceThreshold) * 50;
      }
    }
  }

  return score;
}
```

Figure 57 – Function to Calculate Score

6.8 Large Domestic Product Dispatch

Following the process outlined in section 5.3.8, the implementation begins when the worker selects the Verify button (Figure 58). This action brings up the invoice scanning interface (Figure 59), followed by a display of multiple cards, each representing a product (Figure 60). To verify each product, two steps occur: scanning the EAN13 barcode and the serial number (Figure 61 and Figure 62). Once verification is completed for all items, each product card receives a checkmark, and a green button appears, indicating the process is complete (Figure 63).

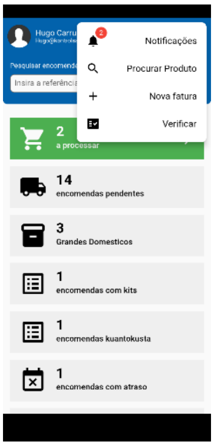

Figure 58 – Menu to Verify Large Domestics

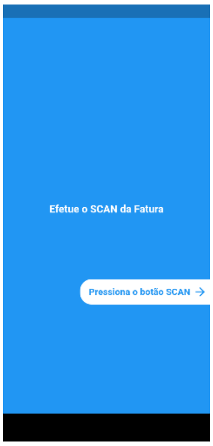

Figure 59 – Invoice Scan

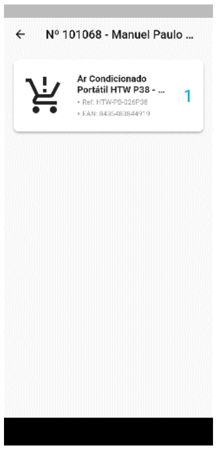

Figure 60 – Menu products Large Domestics

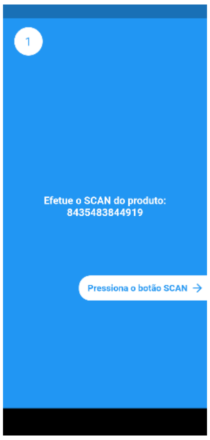

Figure 61 – EAN13 Scan

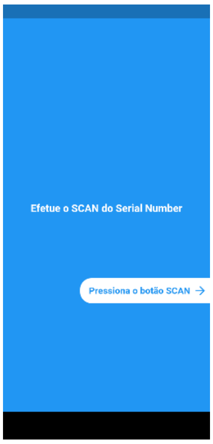

Figure 62 – Scan the serial numbers

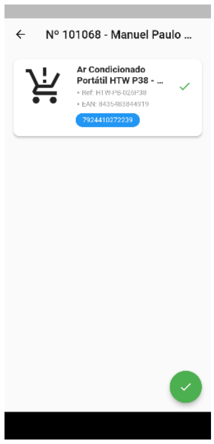

Figure 63 – Product verified

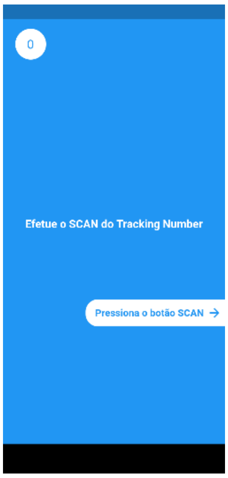

Figure 64 – Tracking numbers scan

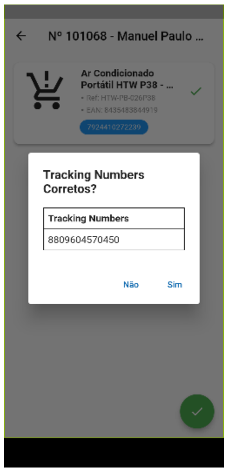

Figure 65 – Verify Tracking Numbers

The final step is to scan the tracking numbers (Figure 64). A dialog box listing all the tracking numbers appears for a final confirmation (Figure 65). If a rescan is needed, a double-click on the serial number, represented by a blue tag on each product card, allows for the serial number to be rescanned (Figure 63). The message sent to PrestaShop includes the verified status, along with the employee's identification and the time of the operation, which is displayed in the back office (Figure 66).

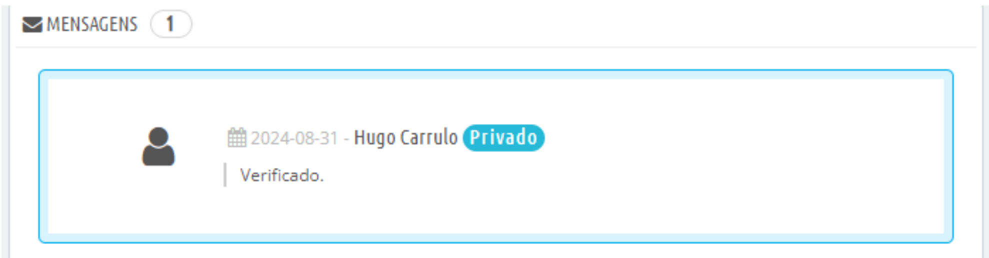

Figure 66 – Message verified in PrestaShop

6.9 Product’s information

Referring to the process outlined in section 5.3.9, the implementation enables users to initiate a product search by selecting the magnifying glass icon labeled 'Search' (Figure 67). This action opens the search interface, allowing users to enter the product name, EAN13, or reference number. For example, searching by the reference 'Z10' displays all corresponding products, as seen in Figure 68. Each card shows product details and tags that indicate stock levels, green for available stock, and red for 'out of stock' if stock is zero. The data source is indicated by an icon located in the bottom right corner of each card.

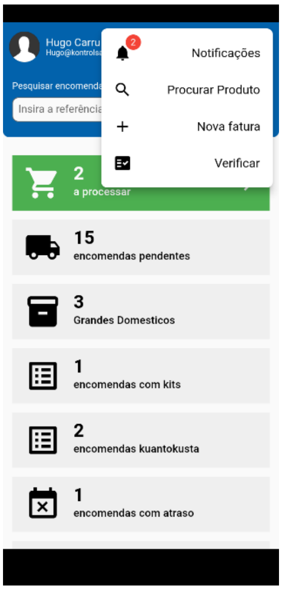

Figure 67 – Menu to Search Product

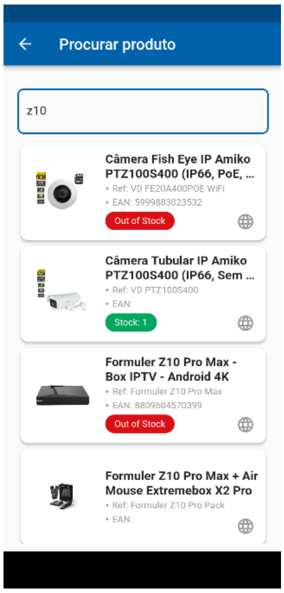

Figure 68 – Search menu with the filter

Product information is displayed in a table, providing detailed data about the quantity and location of each product, along with attributes such as height, weight, and length in input fields (Figure 69 and Figure 70). After clicking the pencil icon, the product's dimensions can be modified in these input fields, as shown in Figure 71.

Figure 69 – Product info

Figure 70 – Product dimensions

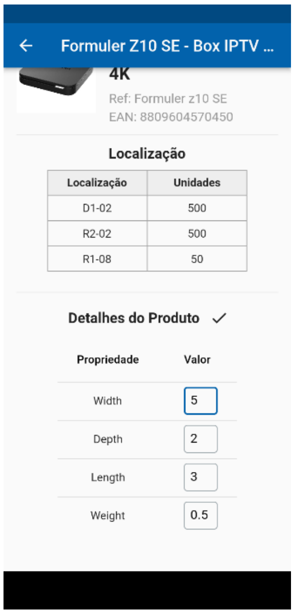

Figure 71 – Edit product dimensions

To search for a specific order, users can enter the order details in the text box at the top of the initial screen (Figure 72), which will display all related information for that order (Figure 73).

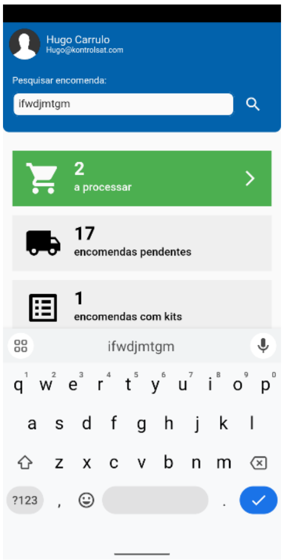

Figure 72 – Search of the order

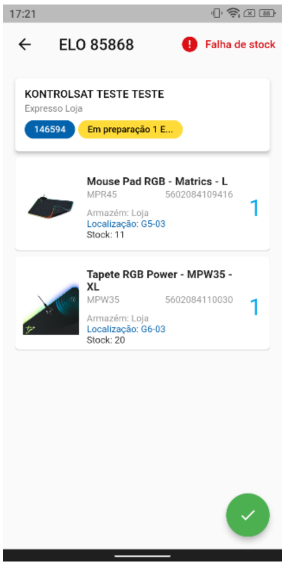

Figure 73 – Show the items in the order

7 Experimentation and Evaluation

To validate the entire implementation, it was necessary to test the PDA in a real warehouse environment and evaluate the results.

7.1 Picking Process

The picking process was the first area to be tested after integrating the scanner. This initial phase presented several challenges: while using the scanner brought clear advantages, it was crucial to ensure that the process wouldn't slow down significantly by requiring every product to be scanned. To assess the overall impact, two sets of tests were conducted, each involving 5 orders with a total of 20 products.

1. **Single User Test:** In this test, a single user completes the picking process for a set number of orders. The goal was to observe whether the new system, with its verification steps, would slow down the process for one user compared to the old system.
2. **Two Users Test:** In this test, two users completed the same picking process, with orders being logically distributed between them. The objective was to measure whether the time saved by having two users using the new system would offset the additional time taken for verification.

The results of these tests are visible in Table 1**:**

Table 1 – Evaluation Results: Picking Process with Single and Multiple Users

Test	No. Of Users	Old System (Seconds)	New System (Seconds)	Time Difference (%)
Test 1	1	302	347	-15%
Test 2	1	317	358	-13%
Test 3	1	311	341	-10%
Test 4	2	304	225	26%
Test 5	2	315	218	30%
Test 6	2	322	209	35%

With one user, the new system took longer due to the additional verification processes, resulting in a time increase of 10-15%. Although this added time may seem like a drawback, it helps prevent errors and ensures that the picking routine doesn’t need to be repeated.

When two users worked together, the new system performed much better than the old one. The logical distribution of orders between users helped reduce picking time significantly, with improvements ranging from 26-35%. On average, the new system reduced the total picking time by 30%, demonstrating its efficiency when multiple users are involved.

Impact of Order Volume on Picking Time

In addition to examining the effect of the number of users on the picking process, the next phase of experimentation focused on how the volume of orders influences picking time. With the new system's ability to logically distribute orders between users, it was hypothesized that as the number of orders increases, the time difference between the old and new systems would grow in favor of the new system.

For this test, the orders were split between three users, and the results are visible in Table 2.

Table 2 – Evaluation Results: Impact of Order Volume on Picking Time

Test	No. Of Orders	Old System (Seconds)	New System (Seconds)	Time Difference (%)
Test 1	20	917	698	23.9%
Test 2	30	1367	972	28.9%
Test 3	40	1794	1173	34.6%

The results demonstrate that the new system becomes increasingly efficient as the number of orders grows. With 20 orders, the time difference between the old and new systems is approximately 23.9%. As the number of orders increases to 30 and 40, the time savings grow, reaching 28.9% and 34.6%, respectively.

This trend highlights how the logical allocation of orders in the new system helps reduce processing time as the workload increases.

7.2 Order Organization and Cube Allocation

Later, it was tested whether using cubes for organizing products by order would be advantageous. When all 32 cubes were filled, no additional orders could be claimed for picking. This system meant that when the carrier arrived, most orders were ready for dispatch, reducing delivery times.

The new system streamlined the process by allowing employees to assign products to cubes efficiently instead of searching through carts to complete an order. Comparing the distribution of products by their orders between the old and new processes, the results are shown in Table 3.

Table 3 – Evaluation Results: Cube Organization for Product Allocation

Test	Number of Products	Old System Time (Seconds)	New System Time (Seconds)	Time Reduction (%)
Test 1	20	122	106	13.1%
Test 2	25	150	128	14.7%
Test 3	30	183	155	15.3%
Test 4	40	246	205	16.7%
Test 5	50	312	259	17.0%
Test 6	60	374	307	17.9%
Average	**37.5**	**231.2**	**193.3**	**15.8%**

Conclusively, as the number of products increases, the system demonstrates improved efficiency. Although it is necessary to scan both the products and the cubes, it is much faster because employees can scan any product in any order and assign it to the corresponding cube without the need for excessive attention, making the process smoother and avoiding time loss.

7.3 Additional Evaluations

Following that, the material reception process was tested. The PDA, being mobile allowed for product reception to take place directly at the rear of the warehouse, eliminating the need to transport items unnecessarily. Additionally, having all operations centralized in one software system simplified the workflow. Communication with TRELLO was successful 100% of the time, ensuring that every process was logged. The requirement that products were only stored after updating their information also ensured data consistency.

The label printing feature proved particularly beneficial, especially for products that lacked EAN13 codes. Previously, such products had to be identified by visual comparison to their photos. Although manual labeling was possible through a billing station on a PC, it was rarely done by staff.

Stock replenishment was one of the biggest advantages. Previously, when items ran out at the picking locations, employees had to search for products on pallets, often lowering the wrong ones. Initially, it was necessary to update the quantities on pallets due to the lack of this information, but after this step, the process became smooth and practical. The correct pallet was always lowered, corresponding to the location of the desired products. This was made possible because the product location was registered during the material reception process.

For managing out-of-stock orders, the selection of orders for out-of-stock assignment was handled more logically, and once the missing product was received, it was automatically allocated to the corresponding order, minimizing waiting times.

In the case of large domestic appliances stored in the second warehouse, this process was one of the most critical. It ensured that mistakes were never made in shipping these products or sending them to the wrong address. These errors were the company's responsibility, not the carrier's.

Finally, the ability to view all product information facilitated resolving any issues raised by management.

In conclusion, this process significantly improved the accuracy and efficiency of warehouse operations, reducing errors, and improving customer satisfaction.

8 Conclusions

Warehouse management has proven to be highly challenging, with processes varying significantly from one company to another, making it difficult to define a one-size-fits-all solution. It was crucial to create a solution that would help the employees and enhance overall operations, it was imperative to have a thorough understanding of the issues at hand. The development process was iterative, and many of the first ideas for solutions were eventually abandoned since they brought more drawbacks than benefits. In the end, however, a system was developed that effectively accomplished the primary objectives outlined at the beginning of the thesis.

8.1 Objectives Achieved

The project's goals were all effectively met, significantly improving Kontrolsat's warehousing operations. With improved scanning capabilities, the new PDA-based system enables precise data capture and synchronization with other systems, like SAGE, RMA, and PrestaShop. As a result, picking and stock management procedures in warehouses are now more accurate and efficient. The company's data management is now improved by the constant updating and real-time accessibility of product information. Also, system intercommunication was strengthened, enabling data sharing across all important platforms. The implementation of specialized handling processes for large home items has resulted in a reduction in errors and an improvement in the efficiency of product management. Overall, the solutions provided a solid foundation for both current needs and future enhancements.

8.2 Challenges and Limitations

One of the notable limitations encountered during the implementation phase was related to the integration of the scanner. During the project's development, having the scanner functional was a main task necessary to begin the other developments. However, due to the problems found with the scanner, all other features were delayed from the predefined timeline. The temporary solution for managing the integration relied on Android Debug Bridge (ADB) commands, making it clear that a more reliable and lasting solution is required. Resolving these issues will take further investigation and collaboration with device manufacturers to ensure successful long-term integration.

8.3 Future Improvements

Looking forward, several enhancements have been planned to extend the functionality of the system. A sophisticated mathematical algorithm will be implemented to refine the picking route definition, allowing workers to retrieve products by taking the most effective routes. Additionally, a desktop application is planned to facilitate better visualization of all warehouse activities and offer administrative control over system settings. Lastly, a specialized algorithm for optimizing stock allocation would automate product placement in the warehouse.

8.4 Final Assessment

To sum up, the project proved to be highly ambitious, facing numerous challenges both in defining and implementing the solutions, highlighting the complexity involved in warehouse management. Despite these hurdles, the project successfully achieved its objectives and established a solid foundation for future enhancements that will continue to improve operational accuracy and warehouse efficiency.

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