

Improving Logistic Processes: Storage, Picking & Kitting in a medium voltage switchgear factory unit

Tiago André Afonso Nicolau

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Supervisor from FEUP: Prof. Jonas Lima

U. PORTO

FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

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Abstract

Facing the increasingly competitive global market, it is in great interest of companies that wish to remain on the forefront of their industry to have an introspective and critical look into the methods and processes they employ, in order to improve them through the reduction of costs and wastes.

This project was developed in the Switchgear industry, where part and process variability is high, leading to a variety of possible improvements which can be applied to other manufacturing industries.

By taking a Lean Thinking approach, in this case, the focus was to eliminate waste, by reducing Picking & Kitting time expenditure which translates to costs, improving Inventory tracking and streamlining employed procedures. Processes were reviewed in an effort to identify areas where the magnitude of potential improvement is highest. Data was compiled through experimental testing and digital system data sets.

Once these improvement areas were identified, through literature review and brainstorming with workers, improvement solutions were proposed. These include: altering locations of Stock Keeping Units based on affinity and demand, further developing WMS-ERP interaction to improve order picking and improve stock difference error tracking as well as using an Excel tool created for this purpose.

There is a high focus on data gathering and analysis as a method of visualizing improvements and results. WMS and ERP historical data, gemba walks, contact with workers, spaghetti diagrams are some examples of concepts developed throughout this thesis.

Results for the improvement measures were assessed through past activity data and expert workers' expectations and were significantly positive across the three goals in the scope of the project, with decreases in order picking time and increases around inventory certainty.

Resumo

Para enfrentar um mercado global cada vez mais competitivo, está no interesse das empresas que desejem manter-se na vanguarda da sua indústria serem capazes de se observarem de forma introspectiva e crítica relativamente aos seus métodos e processos, de forma a melhorá-los, reduzindo custos e desperdícios.

Este projeto foi desenvolvido na indústria de Aparelhagem, com um grau de variabilidade de peças e processos elevado, levando a diversas soluções de melhoria que podem ser aplicadas noutras indústrias de manufaturação.

Tomando uma abordagem de Lean Thinking, neste caso, o foco deve ser eliminar desperdícios, quer seja através da redução do tempo gasto em Picking & Kitting que se traduz em custos, melhoria do controlo de Inventário e ainda melhorar os procedimentos utilizados. Os processos foram revistos com o propósito de identificar áreas onde o potencial para melhoria é superior. Os dados foram compilados através de testes experimentais e extração de dados dos sistemas digitais.

Assim que foram identificadas as áreas de possível melhoria, através da revisão bibliográfica e de brainstorming com outros colaboradores, foram propostas medidas de melhoria. Estas incluem: alterar localizações com base em afinidade e procura, desenvolver a interação WMS-ERP para melhorar as ordens de picking e o acompanhamento dos erros de diferença de stock, assim como o uso de uma ferramenta em Excel criada para o mesmo propósito.

Há um foco elevado na obtenção e análise de dados como forma de visualizar melhorias e resultados. Dados históricos de WMS e ERP, gembas walks, contacto com colaboradores, diagramas spaghetti são alguns dos exemplos de conceitos abordados nesta dissertação.

Os resultados obtidos foram avaliados através de dados de atividade passada e das expectativas de colaboradores mais experientes e foram significativamente positivos relativamente aos três objetivos no âmbito do projeto, com diminuições no tempo de picking assim como um aumento da certeza de inventário.

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"The best way to predict the future is to create it."

Peter Drucker

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Acronyms and Symbols

KPI	Key Performance Indicator
WMS	Warehouse Management System
ERP	Enterprise Resource Planning
SKU	Stock Keeping Unit
SLAP	Storage Location Assignment Problem
OPP	Order Picking Problem
AMT	Aparelhagem de Média Tensão (Medium Voltage Switchgear)
FTE	Full Time Equivalent

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Chapter 1

Introduction

Constant growth and innovation have been key factors in maintaining a competitive edge over other companies in an ever-increasing global market. As technological applications compound and become widely available, there is a general disregard for looking back into a company's own processes and eliminating potential time-wastes and unnecessary expenses.

The project presented results from the Dissertation Project of a Master's degree in Mechanical Engineering in the Production Management specialization, in FEUP. It was developed at EFACEC as a means to promote direct contact with an entrepreneurial environment. The objective for this project was to optimize and improve logistic processes in the Switchgear business unit at the Arrozeira industrial center, in Porto.

In this first chapter, EFACEC is presented as a company, including background information related to its development, followed by the context and goals of the project that was undertaken. Next, the methodology employed in order to best approach the project at hand, starting by a full-scale operation analysis, identifying areas of improvement, implementing improvement measures and analysing their results. Lastly, the dissertation structure is described.

1.1 Efacec Presentation

Efacec is a portuguese company focused on developing products and systems with high added-value for areas of energy, engineering and mobility. Currently, Efacec group is comprised of multiple companies scattered around the world, as seen in Figure 1.1, spanning from Europe, South America, North America, Africa and Asia. According to this, only 6 out of 23 companies in the Efacec group are located in Portugal which shows a high commitment to participate in foreign markets.

This project was developed within Efacec Energia - Máquinas e Equipamentos Elétricos, S.A, one of the portuguese-based companies, as part of the Logistics team of the AMT business unit, Figure 1.2.

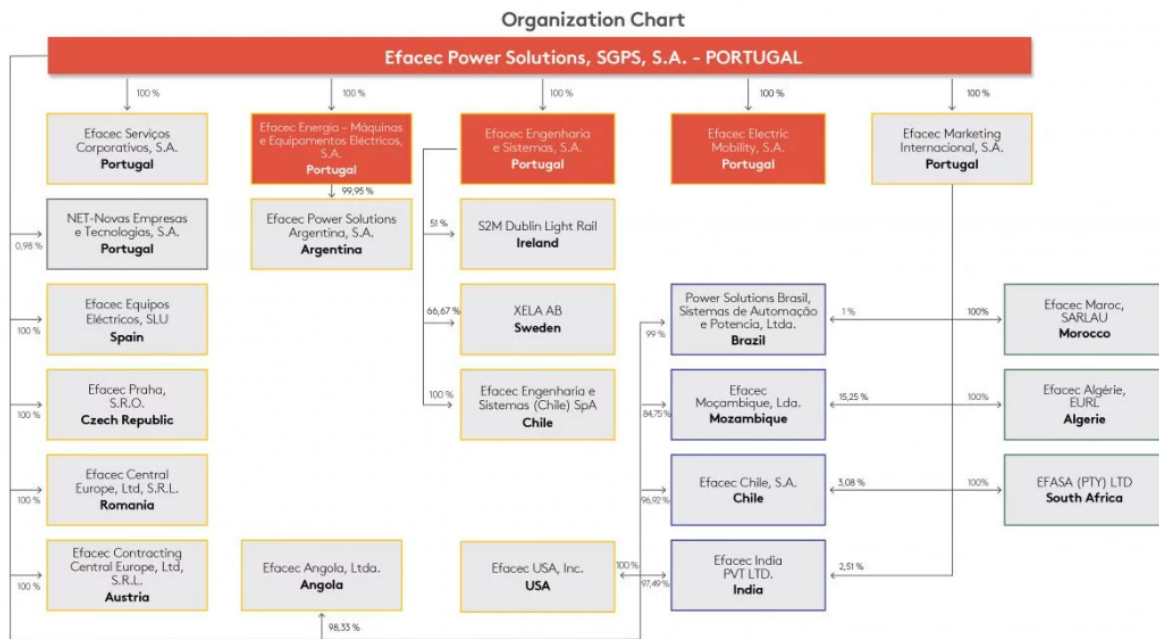


Figure 1.1: Efacec and its global subsidiaries

The Efacec project history dates back to 1905, when a company named Modern, Mechanical Sawing Society was founded. In 1917, they would manufacture the first electric motors in Portugal. Then, in 1921, Electro-Morderna, Lda. was founded, which would be the base company for the Manufacturing Company of Electrical Machines, SARL, founded in 1948, whose capital was distributed among the shareholders, namely Electro-Moderna, ACEC, a belgian business group, CUF, one of the biggest portuguese business groups at the time, and others. In 1962, the name Efacec would be born, and by the end of the 70's they would be one of the first portuguese companies listed on the Lisbon Stock Exchange.

Ever since it's start in the electrical machine industry, Efacec has been on the forefront of

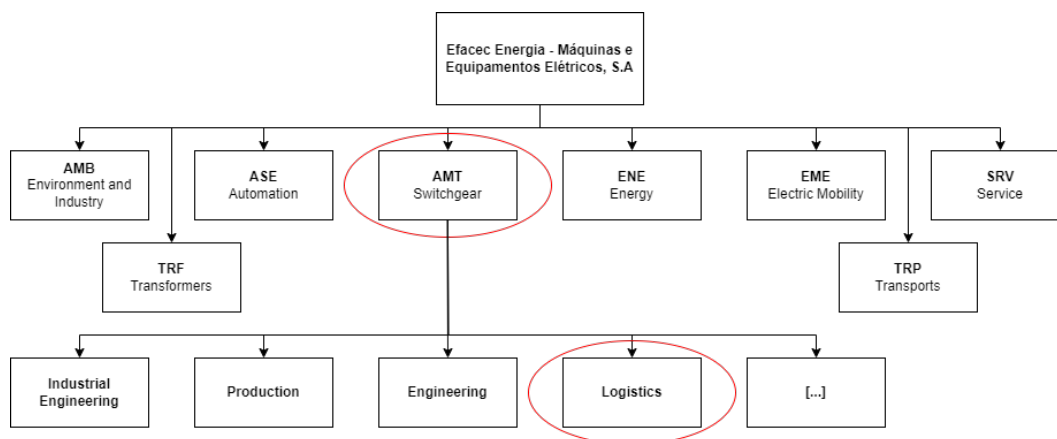


Figure 1.2: Business unit structure of Efacec Energia - Máquinas e Equipamentos Eléctricos, S.A

innovation. In 1976, the company delivers the first three-phase transformer of 420 kV, 315 MVA, with 450 tons, the biggest three-phase unit manufactured in Portugal. In 1998, Efacec reaches 211 million euros in sales Santos (2012). In 2018 it reaches over 430 million euros in sales, according to their Financial Report.

1.2 Project Context and Goals

This dissertation is the result of Efacec's willingness to look for improvements to their current state of logistics operations in their Switchgear unit in Arroteia, Porto. This unit is responsible for the production of switchgear solutions in different voltage types with a high degree of customization and modularity.

The three goals for the project were defined as: the reduction of costs regarding logistic movements, namely the reduction of time spent in picking operations and the betterment of receiving and storing materials; the reduction of stock differences between the Warehouse Management System (referred from now on as WMS) and Enterprise Resource Planning (referred from now on as ERP) systems, as well as identifying root causes for the occurrence of these errors and acting upon them; the improvement of the delivery process of materials for the production and expediting sections of the Switchgear unit, in order to promote a more efficient follow-up work.

1.3 Methodology

In order to approach the issue at hand in an organized and structured manner, a methodology should be followed: in this case, it starts with full-level analysis of the current state of operations, the as-is of the logistics systems and processes of the Switchgear unit, including the collection of data ranging from the warehouse floor plan and storage locations to on-site procedure review in proximity with workers and also data extraction and analysis from WMS and ERP for current and past activity.

Following this, the next step should be identifying areas of improvement, where processes might not be as efficient as they could be, where there might be a need for an entirely new approach. This should be combined with an effort in understanding where other practices and methods from literature review and other sources can be applied or serve as a baseline for the improvements that should be implemented. This could include altering the guidelines for procedures such as material delivery and storage policy, bettering workers formation and creating tracking tools to tackle new stock difference occurrences.

After implementing the proposed improvements, the resulting effects should be monitored in order to understand if and to what degree the changes made were beneficial to the functioning of the factory unit. In order to draw this comparison, some metrics should be defined and tracked before and after said implementations. In the case of some improvement measures, even if they can't be implemented or their results tracked within the scope of this dissertation, they should still be considered from a to-be implemented standpoint.

The summarized methodology approach is represented in Figure 1.3, in which the current state is first assessed, potential for improvement is identified, following this, improvement measures are planned and implemented and lastly the results from these measures are evaluated.

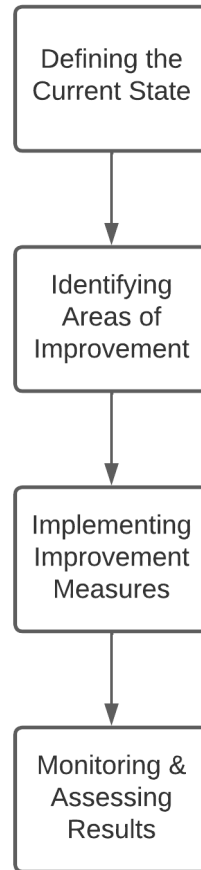


Figure 1.3: Methodology approach employed for the project

1.4 Dissertation Structure

This dissertation's aim is to analyze the state of operations within a company's factory unit and to propose, implement and track the success of measures regarding logistic movements efficiency, WMS and ERP stock difference error mitigation, and defining material delivery processes.

Therefore, this study is comprised of six chapters:

First, an introduction for the dissertation, wherein the company and the project are described as well as the methodology approach used and the dissertation structure considered.

Second, a theoretical introduction of logistics concepts pertaining to factory and warehouse activities occurring in the Switchgear unit.

Third, a thorough report on the baseline work methods and systems employed, previous to any measures, including product types, material handling, physical and digital limitations and requirements.

Fourth, an analysis of the data collected from field research and database extraction as well as identifying areas of improvement and measures to be taken in order to raise process efficiency.

Fifth, a post-implementation review of the results achieved as well as expected results from other unimplemented measures.

Lastly and sixth, a conclusion and review of the project developed along with future research is presented.

Chapter 2

Literature Review

In this chapter, logistics concepts are reviewed in a general sense, with a higher degree of focus on warehouse logistics. Many authors' focus when regarding warehouse logistics lies more specifically in distribution center logistics which is often more standardized than in-house production focused warehouse logistics. While some distribution center approaches can be employed or serve as inspiration for developing and improving solutions for logistic efficiency, part variability and product customizability can be a deterrent for many others.

2.1 Logistics

The English term "Logistics" has its origin in 1846, with Swiss General Jomini. The term, then "logistique", in French, is derived from the "Marechal de logis", a military rank that refers to the organization of the military support troops (Tepic et al. (2011)). Regardless of etymology, logistics as a concept is inherent to everything, while varying in terms of how it is engaged with, whether for military or business purposes, or more recently emerging as an area of study in the 20th century (Stock and Lambert (2001)).

Edward Frazelle defines Logistics as "... the flow of material, information, and money between consumers and suppliers." (Frazelle (2002)). The Council of Supply Chain Management Professionals (CSCMP) defines logistics activities as including "... inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers". (CSCMP (2013)) Oxford Learner's Dictionaries defines logistics as "the practical organization that is needed to make a complicated plan successful when a lot of people and equipment are involved".

According to Martin Christopher, modern day companies have been met with new challenges. The globalisation of industrial and commercial operations has caused an increased pressure for companies to extend their reach beyond local markets. Newfound customers located far from the company, as well as new possibilities of sourcing and manufacturing deals around the world, while beneficial, create a demand for efficiently managing the flow of goods and information of

this global web. Consequently, logistics is regarded as a key priority for businesses whose intent is to remain competitive in the ever-changing global marketplace (Mangan J. (2016)).

2.2 Lean Management

Lean is an approach to management of people and processes that considers the resource expenditure that effectively adds value to the customer. When value isn't added, it is considered a waste and should be removed. It makes use of a large array of different tools and methods to assist workers in order to achieve the end-goal of improving processes and reducing waste throughout the system (Sobek II (2011)).

Some of these tools and methods include Value Stream Mapping, Kanban, Gemba Walk, Spaghetti diagram and more. Value Stream Mapping is a method for analyzing the current state and coming up with the future desired state of a system or process since it starts until it arrives at a customer, by mapping the different sub-processes such as transportation or production steps. Kanban is a method of enabling Just-In-Time production, or pull production, where processes only occur when an order is received from the customer, which is unlike the traditional push production philosophy where products are manufactured based on forecasts which will typically lead to a waste in storage of obsolete goods or high lead times. Gemba Walk is a method of acquiring information about the way in which different processes actually occur, by having managers and higher-ups taking a direct contact approach where they can observe real processes first-hand. Spaghetti diagram is a tool that can be used to map the movement of workers or products in the shop floor in order to understand if there are wasteful moments of backtracking or generally less optimal traversal.

2.3 Warehouse Logistics

As part of the supply chain, Warehouse Logistics is a subject of extensive study as it revolves around several factors such as labor force and warehouse design. In an effort to reduce costs, executives need to find innovative approaches to improve processes they deem inefficient. These approaches are related to several key factors of efficient warehousing operations such as storage policy, order-picking routing and strategy, and even technological innovations such as pick-by-light or pick-by-voice, and the use of digital tools such as warehouse management systems. In warehouse logistics, there are a few basic operations: receiving, put away, storing, picking and shipping. Although they can be clearly defined as different concepts, they are closely related to each other and the way in which they are conducted can be fundamental for the efficiency of each other (Avdeikins and Savrasovs (2019)). For example, if a pallet of high-rotation items is stored in a less accessible location, such as a high rack, it can hinder the order-picking by forcing a worker to use a forklift which will result in an undesirable time increase when compared to a floor-level location. The picking operation is regarded as the costliest and most resource intensive of them,

around 55% of the warehouse operating costs (some authors consider it to range between 50%-70% (de Koster et al. (2007))), distributed unevenly between its smaller tasks: Travelling (55%), Searching (15%), Extracting (10%), and Paperwork (20%) (Bartholdi, J. J., Hackman, S. T., 2011). As travelling is the most time consuming portion of the picking activity, companies usually put a greater focus on minimizing travel distances (Tompkins et al. (1996)).

2.3.1 Storage policy and order-picking routing

In order to reduce travel distances and consequently improve order-picking efficiency, two distinct but intertwined problems should be considered: SLAP, storage location assignment problem, and OPP, order picking problem. The SLAP is related to policy and methods used in order to store items efficiently, with the objective of reducing overall handling efforts. The OPP is related to the order in which the orders are picked, that is, the routing strategy followed by the pickers. The complexity lies in the fact that SLAP is an input of OPP, as locations are required to determine the optimal picking strategy, but also a SLAP solution can only be evaluated when a strategy for the OPP is determined (Silva et al. (2020)).

SLAPs are very complex and hard to solve using exact methods, therefore simple heuristics are commonly used in order to reach an acceptable solution. Typically these can be separated into three different categories: random, dedicated and class-based, as seen in Table 2.1 (Hausman et al. (1976)).

Table 2.1: Storage policy overview (Hausman et al. (1976))

Method	Description	Advantages	Disadvantages
Random	Items are stored in a random location. In practice this is usually an empty location closest to the receiving area.	Time spent storing items is low, doesn't require strategy implementation.	Can induce very high travelling time during picking if items are stored in distant locations.
Dedicated	SKUs have a specific fixed location.	Time spent storing depends on distance from the receiving area but is always the same per SKU, more organized. Enables low and consistent travelling time during picking by choosing good fixed locations.	Free locations are a waste of space as you can't store other SKUs there, no flexibility. Hard to implement broadly.
Class-based	SKUs are stored based on their assigned class. This can be based on demand, cost, dimensions and more.	Allows for better organization by dividing SKUs into groups. Higher flexibility compared to Dedicated Storage.	Difficulty in classifying SKUs, some items can have dimensional requirements that would put them in one location, while their demand would place them in another.

SKU affinity analysis is a method used in product management and marketing to identify relationships between different stock keeping units (SKUs) within a product line. It involves analyzing the sales data for a group of SKUs to identify patterns of co-purchase or cross-selling. The goal of SKU affinity analysis is to understand which products are frequently purchased together and to use this information to inform product development and marketing decisions. SKU demand analysis is a method used to forecast the demand for individual SKUs in a product line. This can be done using statistical modeling techniques, such as regression analysis, or more specialized software tools that incorporate data on historical sales, market trends, and other relevant factors. The goal of SKU demand analysis is to provide accurate and reliable forecasts of future demand, which can help companies plan production and inventory management more effectively. Both SKU affinity analysis and SKU demand analysis are commonly used in retail and e-commerce to optimize product assortment and pricing, as well as to develop targeted marketing campaigns. They can also be useful for identifying opportunities for product bundling or cross-selling, and for identifying gaps in the product line that may need to be filled (Kofler et al. (2011)).

OPPs are less complex and their solutions usually follow one or more of several routing policies typically found in literature, as in Figure 2.1, with the goal of optimizing and reducing the distance travelled by pickers. Most commonly, these policies are S-shape, Return, Midpoint and Largest Gap. These assume that the picker can carry all required goods at once without needing to unload in the middle of fulfilling an order, and also that the aisles within a warehouse can be freely traversed on both ends. In the S-shape or traversal policy, the picker will enter an aisle containing a product to be picked and exit it on the other end. In the Return policy, pickers enter and exit through the same end of the aisle. In the Midpoint policy, pickers can go up to the middle of the aisle at most before returning and exiting. In the Largest Gap policy, the picker fully traverses the first aisle, then enters the aisles as far as the biggest gap between items within those aisles and like the Return policy, exits from where he first entered, and then traverses the final aisle before returning to the starting position (Dukic and Oluic (2004)).

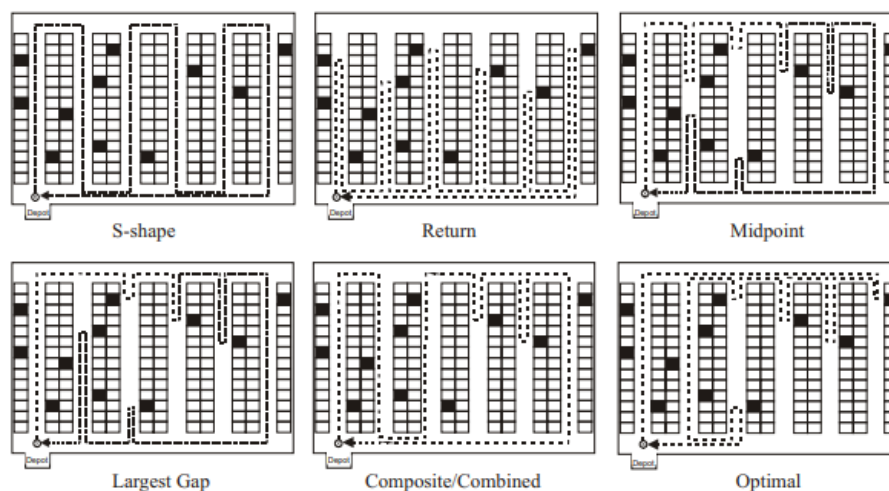


Figure 2.1: Routing policy heuristics

2.3.2 Order-picking strategy

In tandem with the previously mentioned policies, other picking practices should also be considered, with the possibility of simultaneous application. Some of the most common strategies used are discrete, batch and zone picking (Parikh and Meller (2008)). In discrete picking a picker is solely responsible for all the items in a single picking order, this being the simplest strategy but also labor-intensive. In batch picking multiple orders are grouped and picked simultaneously by a picker. In zone picking, each picker is assigned to a certain zone within the warehouse and they are responsible for picking items in that zone only. In the case of distribution centers, discrete picking is often disregarded due to its labor intensity and so batch and zone picking are preferred (Lin and Lu (1999)).

2.3.3 Warehouse Management System

Warehouse Management Systems have been around for a few decades, first appearing in the 1970's under a clothing retail company, J.C. Penney (Armenta (2022)). Since then, these systems have evolved and become more sophisticated with the emergence of new technologies such as barcode scanners and RFID tags. In modern day warehousing, WMSs are usually web-based and can be accessed from anywhere using tablets and smartphones. The usage of technology to aid in managing stock and processes has become a requirement due to the increasing complexity of logistics. In fact, supply chain businesses have been implementing new and effective Warehouse Management Systems in order to stay competitive. Some key features of a WMS can include:

- Inventory management: the system can keep track of stock levels, locations and status of products within the warehouse. It can also be helpful with stock replenishment and inventory control tasks;
- Order management: the system can help in processing orders, including picking, packing and shipping, as well as provide real-time information regarding order status;
- Transportation management: the system can be used to plan and optimize the scheduling of deliveries as well as tracking the movement of products between locations in the warehouse;
- Labor management: the system can be useful to track and manage the usage of human resources and the productivity of workers;
- Reporting and analytics: the system can provide many different reports on warehouse performance and KPIs such as inventory levels, order fulfilment times, productivity;
- Integration with other systems: the system can be integrated with other management systems such as Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM), facilitating the flow of information within the business and providing a more comprehensive overview of the state of operations (Andiyappillai (2019)).

While implementing a WMS is key for a successful business, it can pose several challenges due to being a complex and time-consuming process. The complexity of the WMS is one of these possible problems, as these systems can have many different modules and features that need to be tweaked to each company's specific needs. Related to the ERP and CRM systems, the seamless

integration of these with the WMS can be quite challenging and should be tested and planned carefully to ensure its success. It also creates a need for maintenance to ensure correct functioning of the system and the training of workers to familiarize them with a new method of handling processes and information (Andiyappillai (2020)).

2.3.4 Enterprise Resource Planning

Enterprise Resource Planning (ERP) is a management system that aids organizations in managing and integrating various functions such as accounting, supply chain management and human resources. This provides a single, unified overview of the entire organization. Some benefits of implementing this system include improved efficiency, better decision making due to real-time data that it provides to workers and enhancing communication and collaboration between departments. One of the key differences between ERP and WMS is that ERP systems provide a broad view of the operations while WMS functions specifically for inventory and warehouse management. Similarly to implementing WMS, implementing ERP needs to be thoughtfully planned as some challenges can arise. These can include the level of user involvement and the level of top management support (Al-Mashari (2003)).

2.3.5 Factory Layout Design

Factory layout design is a multidisciplinary, knowledge-intensive task that is key in order for companies to stay competitive in the current global environment (Shariatzadeh et al. (2012)). Designing new factory layouts or reconfiguring existent ones largely caused by fast changes in customer demands regarding product quantity and variety. The usage of simulation tools is crucial to plan a factory layout in order to understand the implications of decisions on strategic, tactical and operational levels (Altarazi and Ammouri (2018)).

According to some authors, there is currently a growing interest in integrating Virtual Reality tools to support research and practical applications related to planning and revising factory layouts. This virtual environment allows users to implement changes and test scenarios before any final decisions are made (Gong et al. (2019)).

2.3.6 Material Handling

Material handling plays a vital role in the supply chain, as it involves the movement and storage of goods from one location to another. There are various types of material handling equipment that can be used in the supply chain, including conveyors, cranes, and forklifts. The selection of material handling equipment should be based on factors such as the nature of the goods being handled, the volume and weight of the goods, and the layout of the facility. In order to optimize material handling in the supply chain, it is important to consider the entire logistics process, including transportation, inventory management, and distribution (Christopher and Towill (2001)).

In a factory setting, assembly lines require the right parts at the right time and place. This can lead to different approaches to the problem: kitting or line stocking. In kitting, parts are

kitted together as part of a group of items, while in line stocking, parts are stocked in bulk at the production lines. These can also be used in a hybrid policy, while not disregarding either of them (Limère et al. (2012)).

2.3.7 Other technological improvement approaches

"Pick by voice" is a technology that uses voice commands to control warehouse operations, such as picking, packing, and inventory management. It allows warehouse workers to use their hands to handle products while still being able to input data into the system. "Pick by light" is a technology that uses LED lights to indicate where products are located in a warehouse and which products need to be picked. The lights guide warehouse workers to the correct location and item, increasing the efficiency and accuracy of the picking process. Both of these have been shown to improve picking order efficiency when compared to more traditional "Pick by paper" methods, as they provide either audio or visual cues, which are more easily interpreted by workers (Haase and Beimborn (2017)).

RFID (radio-frequency identification) is a technology that uses radio waves to communicate between a reader and a tag attached to an item. RFID can be used in warehouse operations for tracking inventory, managing assets, and automating data collection. It allows for real-time monitoring of inventory levels and can help reduce human error in tracking and counting items. Concerns related to this can take several forms: cost, as it can be expensive to implement and the entire warehouse needs to be retrofitted accordingly, interference, as these signals can be affected by other electronic devices or metal objects such as racks, and even security, as RFID tags can be read and cloned by unauthorized individuals, with a potential for data breach or otherwise misuse (Lim et al. (2013)).

Chapter 3

Current State

The factory unit that serves as a basis for this study is Efacec's Switchgear unit in Porto, Portugal. As it currently stands, despite winding down on activity level due to financial constrain, it is still providing customers worldwide with highly customised primary and secondary distribution switchgear solutions.

In this factory unit, there are a high number of unique processes occurring simultaneously, including inbound and outbound logistic processes such as the receiving and handling of materials, the shipping of finished electrical solutions, as well as the in-between production processes of the four different product families it currently harbors.

In order to collect information and data regarding the current state of operations, several methods were utilized, from gemba walks and direct conversations with shop floor workers to utilizing current and historical data from digital systems to understand the frequency and resource expenditure of different operations.

3.1 Primary and secondary distribution products

A business unit's product output is determining in the procedures and methods that can be employed due to the nature of each different industry. Dimensional, handling care and environment control can all be important factors to take into account when envisioning improvements for logistic processes.

In the case of Efacec's Switchgear business unit, the product output in question consists of four different product families, seen in Figure 3.1, which can be split into primary distribution solutions, Normacel and Divac, and secondary distribution solutions, Fluofix and Normafix. These differ greatly in size, Normacel products allow for modularity to fit customer needs and can span across several meters in length and width as well as height, being assembled in factory for testing and then disassembled for shipping, while, in contrast, Fluofix products can be carried on Euro-pallets and Divac products can even be pushed around on wheels.



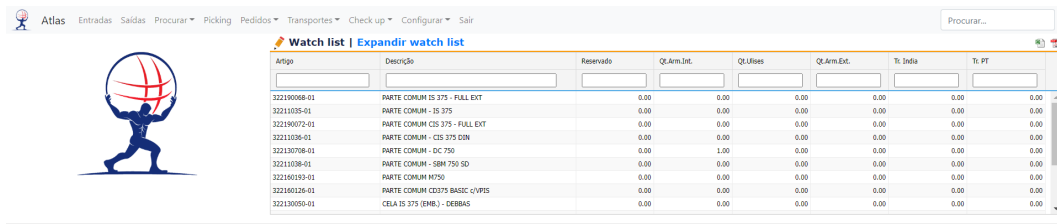
Figure 3.1: Normacel, Divac, Fluofix and Normafix product examples (left to right, top to bottom, sizes not to scale)

The main concern raised by the varied product families as well as the high degree of personalization of production is that by implying a wide variety of stock keeping units it can be unrealistic to standardize procedures globally and instead action needs to be taken on a family-by-family basis. In turn, creating improvement solutions can be more time consuming as they need to be tailored to fit each product family specificity.

3.2 Digital Support Systems

The usage of digital systems in order to more efficiently manage processes and stock movements inside a factory unit has become widespread in the manufacturing industry. In the case of the Switchgear unit, several systems are employed to support workers on a daily basis. The WMS used by the unit is named "Atlas" and is still in early development as it was initially created with prototypical intent. It allows workers to have a detailed overview of SKUs, stock and storage locations, tracks both inbound and outbound movements as well as location transfers, displays

order-picking procedures where workers can directly confirm picking operations on a computer or tablet and can also track incoming overseas shipping.



Item	Description	Reserved	Q-Inv.Int	Q-Inv.Uses	Q-Inv.Ext	To India	To PT
322100008-01	PARTE COMUM IS 375 - FULL EXT	0.00	0.00	0.00	0.00	0.00	0.00
32210005-01	PARTE COMUM - IS 375	0.00	0.00	0.00	0.00	0.00	0.00
322100072-01	PARTE COMUM CIS 375 - FULL EXT	0.00	0.00	0.00	0.00	0.00	0.00
32210036-01	PARTE COMUM - CIS 375 DIN	0.00	0.00	0.00	0.00	0.00	0.00
322100708-01	PARTE COMUM - DC 750	0.00	1.00	0.00	0.00	0.00	0.00
3221008-01	PARTE COMUM - SEM 750 SD	0.00	0.00	0.00	0.00	0.00	0.00
322100193-01	PARTE COMUM M750	0.00	0.00	0.00	0.00	0.00	0.00
322100136-01	PARTE COMUM CDS375 BASIC-11PIS	0.00	0.00	0.00	0.00	0.00	0.00
32210005-01	CELA IS 375 (EMB.) - DEBRAS	0.00	0.00	0.00	0.00	0.00	0.00

This is a functional software prototype under development by Switchgear BU. Contact the Switchgear Industrial engineering team for support.
Digital Office and the IT Service team DO NOT provide support for this software.

Este software é um protótipo funcional ainda em desenvolvimento pela UN Aparelhagem. Se necessitar de apoio contacte a equipa da Engenharia Industrial da Aparelhagem.
O Digital Office e a equipa de suporte IT NÃO providenciam apoio para este software.

Figure 3.2: Atlas WMS interface

One of the most important systems from a company standpoint is the Enterprise Resource Planning (ERP) system, in this case named "Infor Baan" (commonly referred to as "Baan"). As mentioned before, an ERP is a system that is used in order to have a single unified overview of the entire company, which include production orders, economic stock tracking (it accounts for items that might not have been physically used yet but are reserved as part of an order), financial indicators, time-tracking and other functionalities. To a large extent, Atlas and Baan work in tandem, while Atlas serves the unit on a basis of what's physically present in the warehouse, Baan rather works on a more business oriented point of view. Some of the integration between them includes consuming stock in Baan when an item is picked for production in Atlas and creating picking orders based on production orders seamlessly.



Figure 3.3: Baan ERP interface

Other systems are also integrated in the WMS and/or ERP, "Check-in" is a system that supports the receiving of items and allows workers to seamlessly input received products into Atlas and

Baan by running a bar code scan or typing the order identifier. Another of these systems is the Ulises system, a computerized grouping of four Vertical Lift Module storage units. These storage units function as tall series of shelves which are automatically brought into an access window in a part-to-picker philosophy. Ulises is integrated into Atlas and is used to store items as well as fulfill picking orders. At the click of a single button, workers transfer the information regarding what items to pick from these storage locations to Ulises, proceed with the picking procedure by gathering the items from the displayed shelves and once concluded click another button on the WMS to confirm that they picked all Ulises items.

While system synchrony and seamless integration is crucial for an effective management, some of these systems are not fully in sync. One example of this happens when receiving orders. Workers first enter the items into Atlas, as they physically arrive at the warehouse. Only after a positive inspection workers can enter the items into Baan, by entering the buy order identifier. This means that for a certain period of time, items have entered the WMS but not the ERP, which can cause uncertainty for decision makers. Another concern is related to picking orders due to the fact that all available parts from a production order are consumed in ERP at the start of the order-picking procedure before it is even physically retrieved and confirmed in WMS. This means that the systems have an approximate synchrony, but not total.

3.3 Factory layout

The factory layout of any manufacturing unit is of great importance due to the physical limitations and constraints that every selection or arrangement of machines, material handling paths, storage types and locations and even the building's area and size inherently inputs. This means that in order to properly assess what is or isn't possible and how processes are conveyed, a thorough layout assessment is required.

EFACEC's Switchgear unit is especially complex due to the nature of the products developed and produced there. This unit is comprised of four distinct production lines each with their own quirks and manufacturing approaches. Consequently, a significant portion of the factory unit's shop floor area is occupied by manufacturing equipment and in the case of fixed-position production lines, the area occupied due to ongoing manufacturing orders, which can vary in an order to order basis. In addition to this, there are multiple warehousing facilities where items can be stored, some are exclusively for item storage and others are stored in the same distinct areas as production lines. In Figure 3.4, the layout of the unit can be seen as well as the different areas which are explained further in detail below. For a larger figure, see Appendix A.

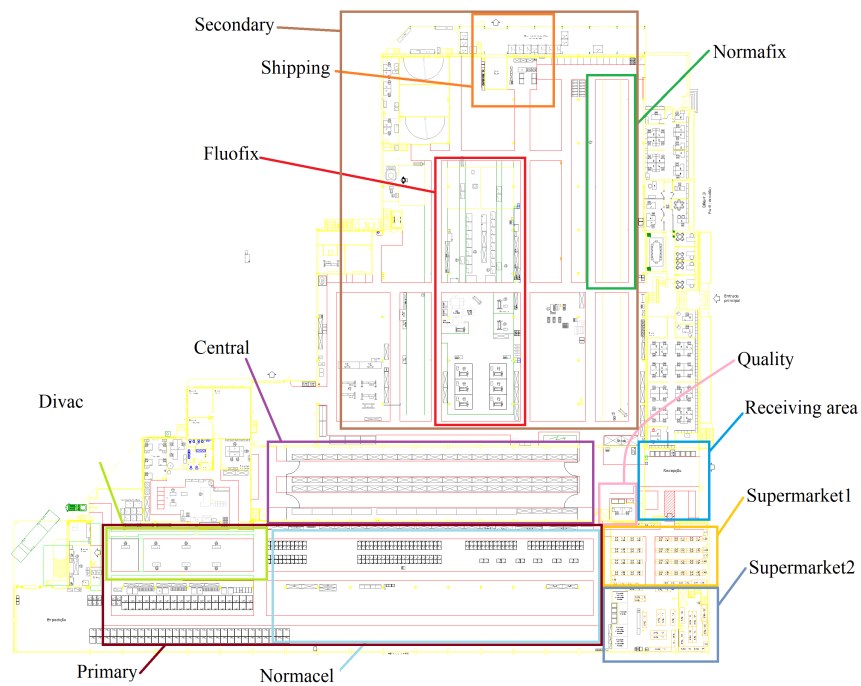


Figure 3.4: AMT unit layout with identified work areas provided by Efacec

Keeping in mind the previously mentioned configurations, the distinct physical areas within the whole factory unit that are relevant for this study are the following:

- The Receiving area, where goods are delivered either by local suppliers by hand or truck, or shipping containers from abroad such as from Efacec's factory in India. It usually requires the presence of a worker with stacker know-how, as many items are palletized for handling;



Figure 3.5: Receiving area

- The Central warehouse, directly connected to the receiving area, is the storage area with the highest volume capacity, containing four rows of three-story-high racks. This type of storage is ideal for bulkier sea-shipped wood crates and large-sized products, of which some require pallets. Aside from a stacker, this area also requires a reach truck for the third story of the racks;



Figure 3.6: Central warehouse

- The Quality control area, located within the Central warehouse. Often times, material will be directed here from the receiving area if the initial inspection deems it necessary, or if at any point during handling or production an item is deemed faulty or a nonconformity;



Figure 3.7: Quality control area

- The Supermarket1, which is, as translated, a supermarket type storage facility for medium to small-sized parts (in this case, mostly copper bus bars) with shelves, all of which are within hand reach as to not require any means of external assistance like stacker trucks;



Figure 3.8: Supermarket1 storage area

- The Supermarket2, in the same fashion as the previous area, another supermarket facility with several types of storage. It is composed of a lower deck storage area with deep bucket-like shelves (identified as P0 - floor zero) for small parts, the main zone (identified as P1 - floor one) that works in a similar fashion to Supermarket1 with regular shelves for storage but also includes the access to the four Vertical Lift Module storage systems (collectively named Ulises) which serve as an efficient and easy to use part-to-picker system. There are also two mezzanine floors (P2 and P3 - respectively, floor two and floor three) with stairway access and a cargo elevator which is only indicated for material transport. This is where parts with lower frequency of use and typically stored.



Figure 3.9: Supermarket2 storage area

- The Primary area, where primary distribution solutions are produced in two zones, Normacel and Divac. Normacel products are assembled in a fixed-position configuration, where the product stays in one place and workers and machinery move to it as needed. As for the Divac, their production setup is comprised of six identical workstations wherein each worker assigned to one workstation is in charge of their individual Divac. This is one of the two facilities where workers

can be aided by a moving ceiling mounted crane when dealing with heavy weights such as some product components and assembled products. This warehouse has a long row of storage racks for materials directly related to the production processes which occur here, such as metal panels but also other varied items needed for the production these two item families.



Figure 3.10: Primary warehouse

- The Secondary area, where secondary distribution solutions are produced in two zones, Normafix and Fluofix. Normafix production happens in a fixed-position configuration, similarly to Normacel, although with significantly smaller dimensions. Fluofix products are assembled in a production line where the assembly happens along. This line extends from one end of the warehouse section to the other, meeting right near the shipping area. Secondary is the second of the two facilities that is aided by a moving ceiling mounted crane, with particular use in the Fluofix line to aid in lifting heavy loads. This warehouse has several three-story-high racking shelves, some near the start of the Fluofix line for storing semi-finished goods and large dimension metal parts. On the opposite end, the racks serve the purpose of storing finished products which await shipping. It is also frequent to store finished products at ground level on top of pallets.



Figure 3.11: Secondary warehouse

- The Shipping area which is located within the Secondary warehouse and serves the sole purpose of outbound logistics, where products are loaded onto the transport operators and sent on their way.



Figure 3.12: Shipping area

- The remaining areas represented on the layout floor plan are lower interest areas such as the offices, break rooms and other shared spaces.

3.4 Material receiving and storage

Material receiving and storage is crucial for an optimized warehouse management, as seen previously in the literature review, the SLAP (storage location assignment problem) is extensively studied due to its impact on the OPP (order picking problem). Therefore, it is important to understand how Efacec deals with the SLAP based on their storage types and limitations as well as how their solutions are conveyed in practice by the warehouse workers. The following is an overview on the processing of items from receiving to storage.

3.4.1 Receiving process

Materials arrive at the unit by road, in shipping containers or smaller trucks. The receiving process starts with unloading the transporter onto the receiving area, or in the case of smaller goods they can just be taken by hand. The orders are checked on arrival and the delivered items are inspected for any defects and only then they enter the WMS. If there are any defective parts such as missing serial numbers or compromising defects such as broken parts they are not entered into the ERP, instead they only enter into the WMS and go to the Quality Control area in Central. If no items are defective, they usually enter the ERP system automatically once the delivery order is confirmed and entered by the receiver on the Check-in system, however this can take up to a few days to happen.

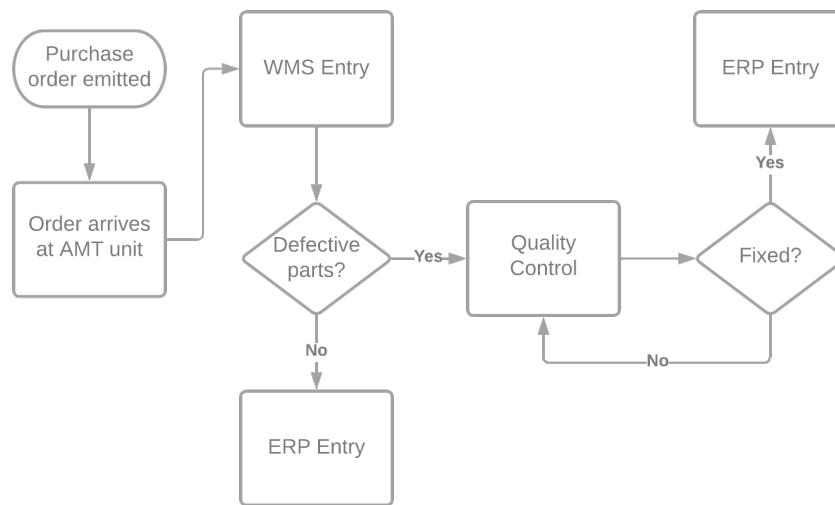


Figure 3.13: Receiving process diagram

Once the items are located in the Receiving area in the WMS, they can then be transported according to a set priority: if there's items missing from ongoing production/picking orders, they can be sent directly to the designated production line/picking tool (i.e picking carts); otherwise, the items are stored according to their dimensions, previous or current locations (if an item is already stored in a certain shelf in a supermarket it will likely be added there as long as there is enough room for it). If the item is larger and designated to be stored in the Central warehouse it will be stored at random in the first available location. There are some restrictions however, wood crates are stored at ground level or on top of other wood crates, under the racks, and products on pallets are placed on the higher racks. As for smaller parts, they are usually stored in the supermarkets and the Vertical Lift Modules mostly according to previous or current locations. All of these movements must be manually inputted by the warehouse worker on the WMS system.

3.4.2 Storage types

Scattered throughout the unit, there are mainly five different storage solutions:

- Shelves, mostly located in the Supermarket1 and Supermarket2, although some can be found alongside production lines where Kanban storage systems are located, as well as consumables such as screws, washers and rivets, which have a very minimal cost and therefore are not tracked by the WMS. The shelves in the supermarkets are used for small and medium-size parts which are suitable for being carried by hand or on a plastic crate. The parts here are stored either directly on top of the shelves' surface or inside plastic crates to ensure that they are located within the correct identified location.



Figure 3.14: Shelves storage location

- Racks, usually requiring machinery to access the items which are mostly wood crates, semi-finished products, metal plates and other pallet requiring items. Located in Central, Primary and Secondary warehouses.



Figure 3.15: Racks storage location

- Vertical Lift Modules, they are located in Supermarket2. These are four tower-like structures with several movable shelves, simultaneously controlled by a computer. Inside them are parameterized plastic crates in which the parts, mostly small sized, are contained. Whenever needed, either for entering items into the system or to take them out as part of a picking order or inventory analysis, the shelf containing the location required is brought onto the user until they confirm the action taken. If there is a sequential action, i.e another item to be picked, the system will then bring that shelf.



Figure 3.16: 3 of the 4 Vertical Lift Module storage systems

- Kanban storage, whenever the inventory level of an item drops and reaches a certain threshold, a card is scanned and an order is automatically sent for restocking, either directly to the supplier or, depending on the case, some Kanban storage is also restocked from the Vertical Lift Modules as a way to more closely track certain parts' consumption. For the most part though, Kanban items are more loosely tracked on a by carton basis since there isn't any way of detecting how full a carton is due to the more liberal nature in which these materials are used.



Figure 3.17: Kanban storage area



Figure 3.18: Scanned Kanban cards

- Floor level storage, some products are stored directly on the floor or other times on pallets which are at floor level. This can happen due to lack of space or simply as a way to more efficiently use otherwise unused locations. While technically items stored under racks could be classified as floor level storage, this definition is not intended to reference those and rather horizontal storage areas.



Figure 3.19: Floor level storage locations

3.5 Material Picking & Kitting and Delivery

In regard to warehouse logistics, the picking process is widely considered as the most resource intensive process, and as a result it is critical to ensure that it is efficient and optimal. The OPP and how Efacec deals with this problem is the main focus of the picking process overview. Material kitting lies in the methodical organization of materials in picking carts, combining parts into kits for each product's assembly.

Combined with this, the delivery process is the procedure of taking the cart to the production line delivering parts in a warehouse-to-line direction, but also in the reverse direction when sending excess or defective parts back and retrieving empty picking carts to initiate new picking orders.

3.5.1 Picking process

One of the key processes of any warehouse operation is order picking. It is frequently targeted for improvement and optimization as one of the most time consuming operations, often being inefficient. Some of the reasons for this include a disregard for an optimal routing algorithm and for the benefits of an item storage strategy with picking orders in mind. The combination of these two can be critical for success. Other strategies might involve technological advancements such as adopting WMS for order picking instead of a pick-by-paper method or even using automated part-to-picker systems for decreasing picker movement.

For the most part, the Switchgear unit's picking orders are pick for production, where pickers will travel between the sub-warehouses and gather the items as listed on their WMS. There are pick for shipping orders as well but these are of lesser importance for analysis as they consist of moving between the shipping area and where the products are stored which will typically be close to it as long as there was room to store them previously.

Initially, picking orders are issued in a frozen state onto the WMS. These are then unfrozen and enabled for picking by the head of the logistics workers if the required parts are available in accordance. Picking orders can still be enabled without all the necessary parts listed in WMS if upper management so decides as some parts can arrive later on in the production stages.

It is important to understand that each production line (Normafix, Normacel, Fluofix, Divac) has different dimensional requirements for their picking orders. This leads to using different picking carts/methods for each, as seen in Figures 3.20, 3.21, 3.22 and 3.23. Due to a limited number of specific carts (i.e there are only 7 Fluofix picking carts) this means that if all carts are currently being used then no other orders can be issued unless there is a decision to adapt other carts (i.e sometimes Normafix carts can be used for Fluofix pickings). Fluofix picking carts in particular have an adaptation to fit bearings and bushings.

3.5.2 Fluofix picking

This product's picking orders start with a worker looking for an available Fluofix picking cart. These are usually located at the line-side, on the edge closest to the Central warehouse. There is no standardized way of letting the pickers know that a cart is free and can be used for an order. Most commonly, production workers will phone pickers informing them.

Once they have a cart, accompanied by either a laptop or a tablet with the WMS picking order, they follow the item location ordering, going through Central, Supermarket1, Supermarket2 and then back to Secondary. While following this path, they will arbitrarily choose in which order they pick: either on the way from Secondary to Supermarket2 or the other way around.



Figure 3.20: Fluofix picking cart

3.5.3 Normafix picking

Normafix picking orders work similarly to Fluofix picking orders. Workers will first look for an available Normafix picking cart which will be located on line-side. This production line extends from the edge to the middle of Secondary and as production is in fixed-position, carts will be randomly placed on either side when emptied. Taking the cart and a digital device for accessing the picking order, workers pick items in Secondary, Central, Supermarket1, Supermarket2 and Ulises, or in the reverse order, and return the cart back to the production line. As it currently stands, to deliver the cart, workers have to directly ask the head of the production line where they should place it. There is no production order identification for each of the fixed-position locations. Similarly to Fluofix, there is no method for indicating that a cart is free to initiate another picking order.



Figure 3.21: Normafix picking cart

3.5.4 Normacel picking

For Normacel picking orders, workers will head to Primary, where production occurs in a fixed-position arrangement. Normacel products have very large dimensions and a high number of different required materials, and as such their picking "cart" consists of a tower-like structure with shelves (as seen in Figure 3.22) which pickers carry around with a stacker due to lacking wheels. In this case, all the items to be picked are usually located in Supermarket1, Supermarket2, Ulises, Primary and Central. These types of picking orders can typically take a few hours of effective picking time, that is if not counting breaks or interruptions, however they can be ongoing for up to months while the product is still being assembled and missing parts continue to be delivered to the factory unit and directed to the fixed-position location. Similarly to Normafix, there is no identification of the production order to facilitate material delivery and there is also no standardized method for indicating when a picking cart is free.



Figure 3.22: Normacel picking tool

3.5.5 Divac picking

In Divac picking orders, batch picking is used instead of the discrete picking method typically used in the other product families. As such, one picking order will contain enough materials for multiple individual finalized products. This is due to Divac orders typically being of multiple products with the same exact specifications and manufacturing steps.

Workers head to Primary to the Divac line to get a pallet. There are no special picking carts for this product, and so pallets are used to carry items with the aid of a pallet truck or a stacker. They then head to Supermarket1, Supermarket2, Ulises and finally Central, picking SKUs along the way, until arriving at Primary next to the Divac line. In this case, production line workers will then sort and separate the items according to each Divac to be produced which expends additional

time. Similar to previous picking orders, there is no indication if a pallet is free to initiate another picking order, but since pallets are abundant workers can grab a pallet that's not in use and then retrieve empty pallets after delivering another order.



Figure 3.23: Divac picking tool

3.5.6 Ulises picking

The Ulises system is used in most, if not all, picking orders. As previously mentioned, it consists of four Vertical Lift Modules, tower-like structures with moving shelves and organized crates of parts, all controlled by a single computer. Whenever pickers arrive at Supermarket2, they issue the Ulises part of the order and the system will load it and start moving the shelves to the window-like access as can be seen in Figure 3.24.



Figure 3.24: VLM access window with a drawn out shelf

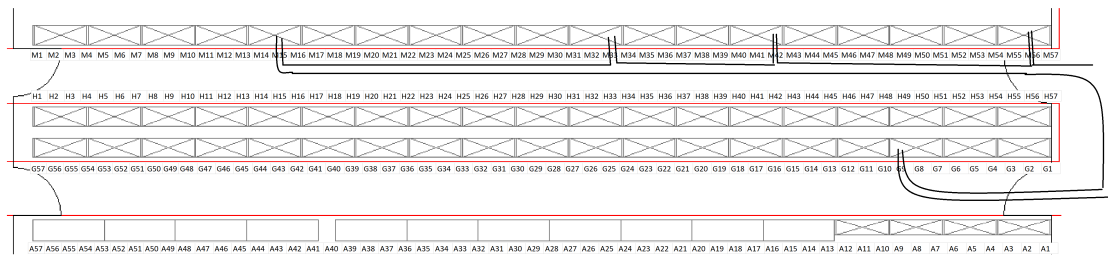


Figure 3.26: Spaghetti diagram representation of a real picking order

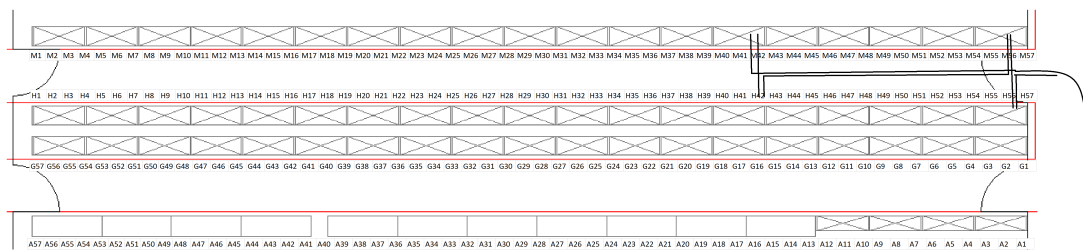


Figure 3.27: Spaghetti diagram representation of an optimized route of a real picking order

Regarding the order of sub-warehouses that the workers visit, there is no automatic procedure implemented in the WMS and workers can at most filter parts according to sub-warehouse. The decision of moving where in what order is up to the workers, however this part isn't problematic as the path to take is linear and as long as the worker doesn't backtrack, it should match the optimal route.

3.5.8 Delivery process

The delivery procedure is inherently tied to the picking procedure as a culmination of the movement pathing, item placement and organization on the picking cart. The procedure employed for this can be explored to benefit the end receiver, that being the production worker that will make use of the collected parts. The reverse operation, delivering parts from production to logistics, is also an important component of the delivery procedures. Sometimes in the process of assembling products, workers will find themselves with defective or surplus material which needs to be dealt with, from an ERP perspective, the production order needs to be partially reversed in order to reenter the extra parts into the system, and from a WMS perspective, the items need to be physically placed back into the warehouse, admitted to the locations and registered in the system.

In the case of this factory unit, delivery procedures regarding getting parts from logistics to production are very scarce. The indications on how to organize materials to benefit the production line only exist for Fluofix, where items are assigned a work station in the WMS picking orders by which the picking workers can organize the parts into boxes. This is identified by a code on the item's line, which requires user knowledge to identify what it means. For the rest of

the production lines, this feature was not implemented due to the higher complexity of the other products' assembly process.

For the reverse process, production workers are indicated to return spare and defect parts to the logistics team as well as indicating this action on the ERP system through partial production order reversal. Physically, workers should store said part in a plastic crate and put it on a designated place for retrieval by the warehouse team, however there is only one dedicated space for this effect which happens to be located at the start of the Fluofix line and serves only this line as well. For the other lines, there is currently no designated area for that purpose and workers will usually place it somewhere near their work station or on the picking carts. Further conversation with warehouse workers revealed that even though there are some indications to enable the retrieval of these parts, production workers adhesion is very low and parts usually end up lost or stacking up on their work stations.

3.5.9 WMS-ERP stock difference errors

When dealing with two different digital systems, their synchronization is essential in order to keep an accurate track of stocks and movements within the warehouse. As it currently stands, Efacec's WMS and ERP systems are not fully in sync which means that at certain points in time one system will not be mirrored on the other. One of this cases is when a WMS picking order is started. In this instance, when the picking order is enabled by the warehouse workers, the ERP system will consume all items to be picked in that order. In the WMS however, items are only consumed when the picker physically takes them from their location and confirms it on their laptop or tablet. Consequently, if a picking order takes a long time, items will be out of sync during that whole period of time.

In order to track these differences, the WMS has integrated a tab that compares stocks from both systems and displays items that do not match. On the 25th of october, 4494 items were deemed as having a stock difference, with an absolute monetary value of over 2.9 million euros. In operational terms, this means that there is uncertainty associated with these items which can compromise or delay production planning and subsequently undermine factory unit's output capacity. In order to determine improvement actions to be taken regarding this topic, further analysis into the processes and intricacies of each system is required.

Chapter 4

Improvement Measures and Results

In order to identify improvement measures that can be implemented, a lot of different aspects of the factory unit need to be taken into account. From product variability to warehouse limitations, each specificity should be considered in order to propose measures that ought to achieve the goals initially established. In the following sections, the measures are distributed according to the goal they are mainly proposed to achieve, however some of them can also have positive effects regarding the other goals. For the analysis of time reduction in the upcoming sections, FTE or Full Time Equivalent was calculated as 8 hours of work, 22 times a month, therefore 1 FTE = 176 hours/month (FTE is a measure of working hours, 1 FTE is equivalent to the time spent by 1 full-time worker).

4.1 Reducing time spent in Picking & Kitting operations and Improving the Receiving and Storing of Items

For the purpose of understanding how time spent can be reduced and picking operations made more efficient, large amounts of data were thoroughly analyzed containing all historical WMS movements including information related to product family, time spent, warehouse location and other aspects. Other sources of data such as which items are currently located in which warehouse were also analyzed. In addition to this, some picking orders were also accompanied and timed in order to establish reference values.

For the sake of efficiently dealing with data, WMS movements were split per sub-warehouse, as from conversations with workers and from accompanying daily activity in the facilities it was clear that time per picked SKU was significantly different between each one. Primary warehouse was advised by the Efacec supervisor to not be considered in the scope of the project due to already existing efforts of restructuring its storage locations, and so no actions were considered for this section. Secondary warehouse was not considered as items in stored in this facility were large structural parts which are picked on a one-per-order basis or are already purposefully located near Fluofix and Normafix production lines and due to no significant gain in relocating them, were discarded in agreement with the supervisor.

With this in mind, Ulises, Supermarket1, Supermarket2 and Central were analyzed. In Supermarket2, a distinction was made between ground level locations which are floor 0 (Piso 0) and floor 1 (Piso 1) and mezzanine locations (Piso 2 and Piso 3) as when accompanying picking orders it was identified that these would have a significant difference because of the time spent going up and down the flights of stairs. From extracting and analyzing historical data with timestamps and storage location tags from the past 3 years worth of WMS entries, Table 4.1 including time per SKU and location was made:

Table 4.1: Average Time per SKU from historical data

Warehouse	Time per SKU (min/SKU)	Qty. of entries
Supermarket 1	01:20	13688
Supermarket 2 (combined)	01:52	12323
Supermarket 2 (ground floor)	01:43	9894
Supermarket 2 (mezzanine)	02:25	2429
Central	05:30	2828

As experienced by workers and discussed in conversation, Central has the highest average time spent per SKU as items located there are usually larger and heavier, often requiring stacker or forklift assistance. Despite that, it is also where less movements happen.

Regarding the Supermarket2 sections, it confirms that they are significantly different in terms of time per SKU, a 41% increase from ground floor to mezzanine locations. It is also important to note that Supermarket1 and Supermarket2 (ground floor) are mostly similar in regards to picking items, both not requiring any special machinery or long flights of stairs. Their main difference is the way in which their shelves are organized, Supermarket1 being more intuitive and standardized. This means the time increase of 29% from one to the other can likely be attributed to Supermarket2 being harder and more confusing to navigate, especially if workers are less experienced.

The Ulises system functions in a different fashion when compared to all other picking methods. Workers input the start of the Ulises section of the order, gather the items through the computer system associated with it, then confirm that all items have been picked which happens all at once. As the Ulises system isn't fully integrated into the WMS, it is unable to track the time spent per SKU.

To corroborate these findings empirically and to provide data on the Ulises portion of picking orders, two Fluofix picking orders were accompanied and timed, as well as their respective spaghetti diagrams were elaborated. These results were organized in Table 4.2, Table 4.3, Figure 4.1 and Figure 4.2. Although the time per SKU was faster across the board, it can be attributed to the fact that these orders were picked for the Fluofix production line, which is the simpler and more frequent product and as such workers familiarity with its typical parts and locations slightly skews these values.

Table 4.2: Average Time per SKU for ATL0018787 picking order

Warehouse	Time per SKU (min/SKU)	Qty. of entries
Supermarket 1	00:45	6
Supermarket 2 (combined)	01:20	14
Supermarket 2 (ground floor)	01:00	10
Supermarket 2 (mezzanine)	02:00	4
Central	05:08	7
Ulises	00:38	19

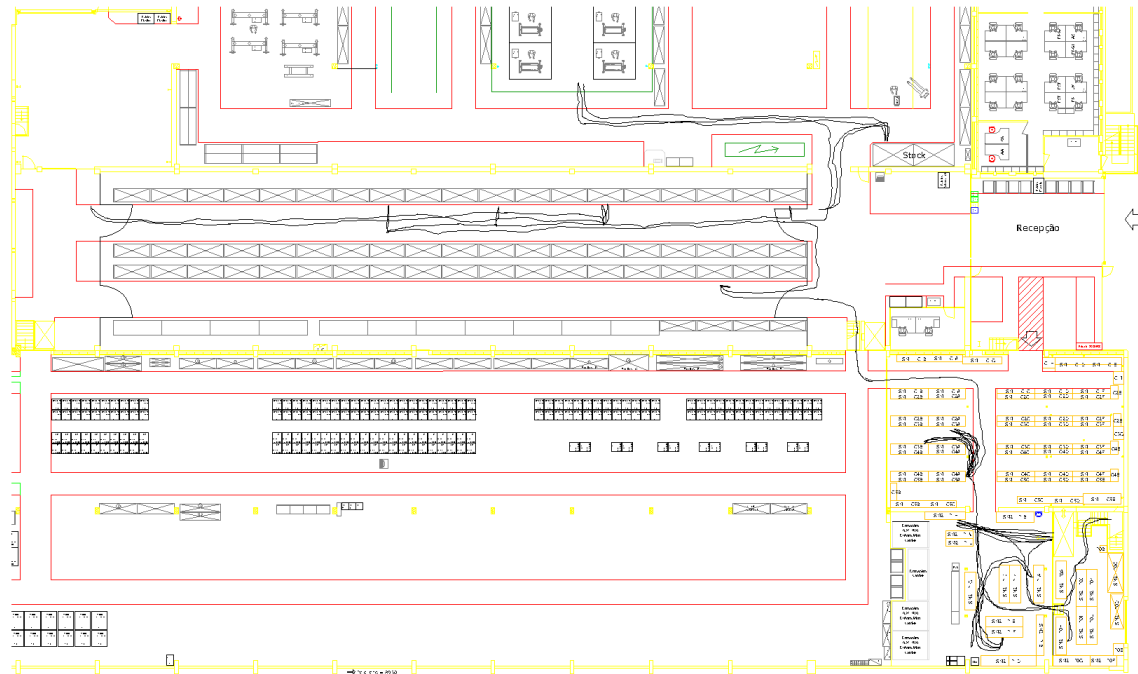


Figure 4.1: Spaghetti Diagram for ATL0018787

Table 4.3: Average Time per SKU for ATL0018788 picking order

Warehouse	Time per SKU (min/SKU)	Qty. of entries
Supermarket 1	00:39	7
Supermarket 2 (combined)	01:02	14
Supermarket 2 (ground floor)	00:45	10
Supermarket 2 (mezzanine)	01:45	4
Central	04:23	8
Ulises	00:37	19

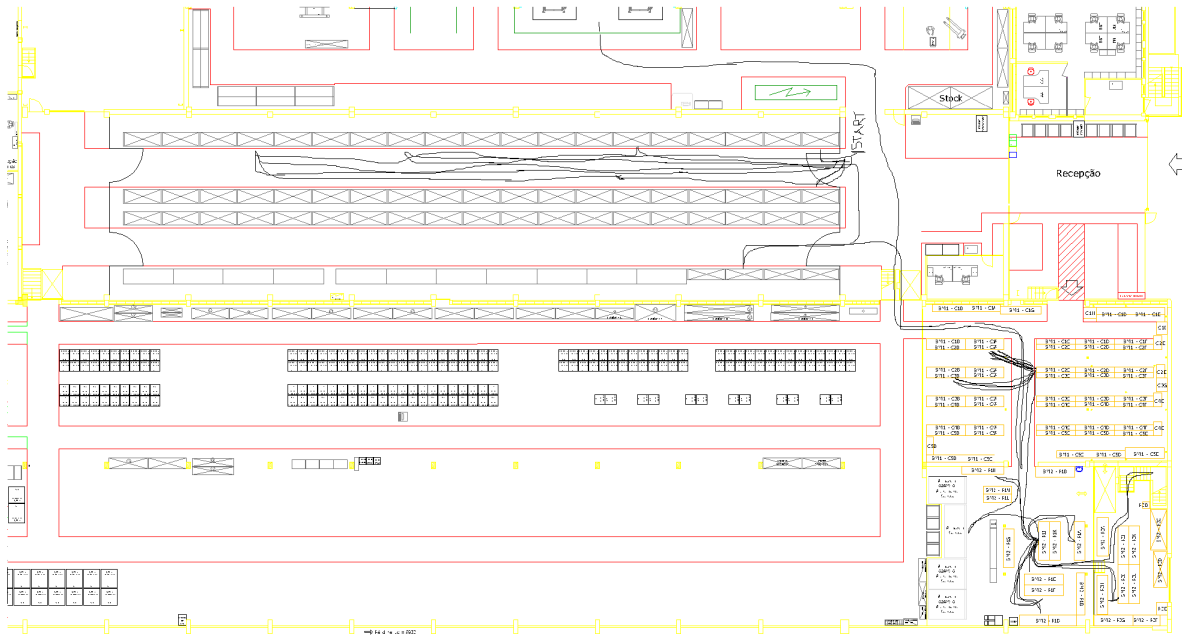


Figure 4.2: Spaghetti Diagram for ATL0018788

4.1.1 Altering item storage locations based on item affinity analysis

This initiative derived from observing the picking orders for the Fluofix line, especially in Central where, as can be seen from the Spaghetti diagrams in Figure 4.1 and Figure 4.2, workers have to move around the warehouse a lot, back and forth, leading to undesirable travelling and therefore wasting time. From here, the idea cropped up to determine what items could be located in close proximity to minimize travelling. These would be stored in a dedicated location in a thoughtfully chosen area of the warehouse, likely to be one of the edges of the racks as it minimizes time spent in travelling into the corridor and back. Usually SKUs have multiple locations, and as such, if one of these dedicated locations was emptied as a result of a picking order, workers should then replenish it by moving one of the crates or pallets from another storage location to the dedicated one. This ensures that pickers only take items from the closest possible location and on top of that they always take items from the same location until its emptied instead of depleting the storage locations in alternation.

The datasets extracted from the WMS contained the picking order ID, product family and warehouse where the item was before it was picked. With this in mind, Excel was used to filter items in Central warehouse into their family products. Once separated, a list of all individual SKUs per product family was defined. Then, in a matrix-like format as seen in Figure 4.3, each SKU was checked against another on all previous picking orders by the use of Excel formulae to count how often two items were picked in the same picking orders, establishing their affinity.

When analyzing each family's results, in conjunction with more experienced personnel, only Fluofix related SKUs were acknowledged as being able to be stored together based on affinity. Within these, some results were discarded as they constitute large metal structures which are

1002		274	198	198	144	127	96	56	52	49	43	42	38	38	37	34	31	31	30
		37308001-	37316500-	37308003-	37317001-	33104351-	33102023-	33105301-	33110892-	33104249-	33108227-	37304014-	331130126	33108056-	33105301-	331120032	322160193	33107140-	331180423
274	37308001-	274	134	149	112	88	61	0	52	0	16	0	1	36	0	0	0	2	0
198	37316500-	134	198	139	0	75	74	0	52	0	0	21	0	35	0	0	0	2	0
198	37308003-	149	139	198	36	46	76	0	52	0	37	0	0	37	0	0	0	0	0
144	37317001-	112	0	36	144	40	0	0	0	0	36	0	0	0	0	0	0	2	0
127	33104351-	88	75	46	40	127	16	0	20	0	1	11	0	23	0	0	0	1	0
96	33102023-	61	74	76	0	16	96	0	6	0	0	2	0	19	0	1	0	0	0
56	33105301-	0	0	0	0	0	0	56	0	0	0	12	0	0	0	0	0	0	0
52	33110892-	52	52	52	0	20	6	0	52	0	0	0	0	0	0	0	0	0	0
49	33104249-	0	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	0	0
43	33108227-	16	0	37	36	1	0	0	0	0	43	0	0	0	0	0	0	0	0
42	37304014-	0	21	0	0	11	2	12	0	0	0	42	0	0	1	0	0	1	0
38	331130126	1	0	0	0	0	0	0	0	0	0	0	38	0	0	0	0	0	0
38	33108056-	36	35	37	0	23	19	0	0	0	0	0	0	38	0	0	0	0	0
37	33105301-	0	0	0	0	0	0	0	0	0	0	1	0	0	37	0	0	0	0
34	331120032	0	0	0	0	0	1	0	0	0	0	0	0	0	0	34	0	0	0
31	322160193	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0	0
31	33107140-	2	2	0	2	1	0	0	0	0	0	1	0	0	0	0	0	31	0
30	331180423	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30

Figure 4.3: Snippet of the Excel affinity analysis

picked once per picking order and can only be carried one at a time, and as such would constitute no benefits in dedicating storage locations as the replenishment movement and subsequent picking movement would be more time consuming than simply moving it from any other location only at the moment of picking. In the end, 10 SKUs were chosen to have a fixed location closed to the edge of the warehouse at ground level.

In tandem with this decision, the routing parameter that is used for deciding which locations to prioritize was altered from higher stock to alphabetical order. While not ideal from a standpoint of being an assumed neutral change in regards to benefiting the overall functioning of the warehouse, it was required in order to ensure that these dedicated locations were always chosen by the Routing procedure, which in turn does benefit the factory unit. The improvement of the Routing algorithm is regarded in a section further down.

As a side note, even though not all items can have dedicated locations, workers should be advised to store items according to their product family, in a very lenient and flexible class based storage policy, in order to facilitate picking: Fluofix and Normafix related SKUs should be stored closer to the right edge of the warehouse (in the configuration seen in Figure 4.1 and Figure 4.2), while Normacel and Divac related SKUs should be stored closer to the left edge of the warehouse in order to not encumber workers in storing the first two product families in their higher priority locations (reminder that items received are carried to Central from the right side, and as such there can be a predisposition to store items on the first or fastest available location, which isn't optimal from a picking procedure standpoint).

In order to have empirical substance to analyze and validate the resulting benefits of dedicating storage locations, a Fluofix picking order was accompanied after moving some of the chosen items. At this time, not all of the SKUs were available to be moved, so the worker still had to move a bit more than what was intended but less than in previous picking orders, as seen in Figure 4.4. The worker was also unaware of the changes made which led to unstacking crates, taking only part of the items, stacking them again and unstacking them yet again after realizing the items were stored together. This means that while the results displayed in Table 4.4 show significant benefits already, worker's familiarisation with the changes as well as effectively applied all of these changes, can reduce picking time even further. This means that the results can be seen as a conservative estimate

of the intended measures and benefits.

Table 4.4: Average Time per SKU for ATL0018790 picking order

Warehouse	Time per SKU (min/SKU)	Qty. of entries
Supermarket 1	00:39	8
Supermarket 2 (combined)	00:45	14
Supermarket 2 (ground floor)	00:45	14
Supermarket 2 (mezzanine)	00:00	0
Central	03:26	7
Ulises	00:37	19

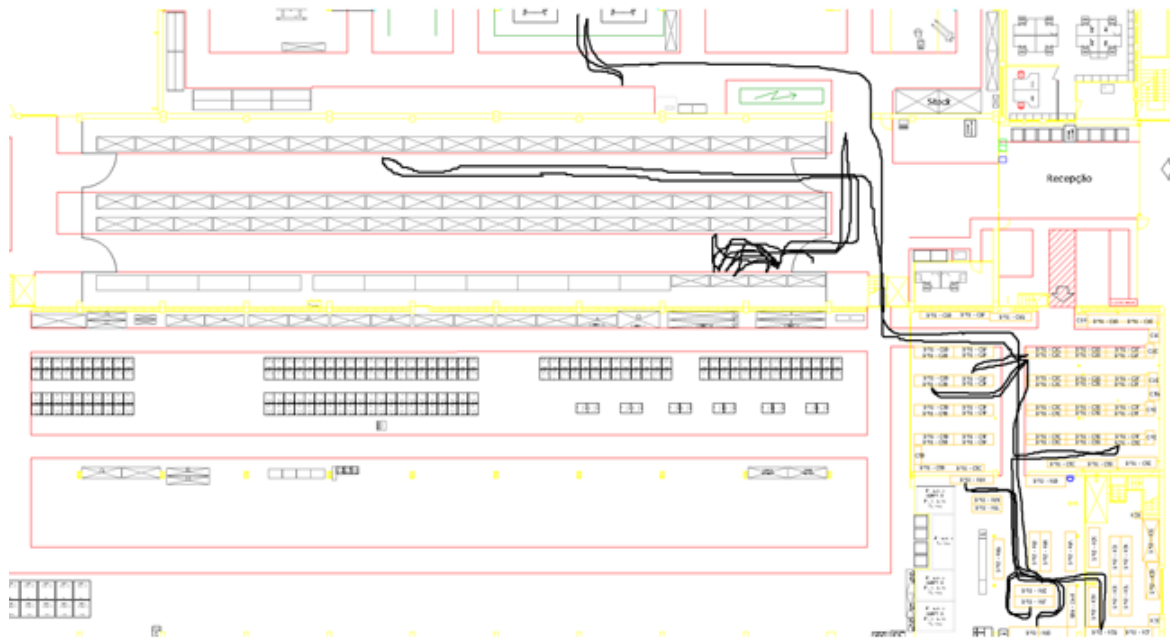


Figure 4.4: Spaghetti Diagram for ATL0018790

When comparing the time per SKU in Central from this picking order to historical data in Table 4.1, there is an improvement of 38%, equivalent to a time gain of 2:04 min. Based on internal future projections for the Switchgear unit, Central is expected to have 600 monthly moves. Based on historical data, proportions were established regarding the monthly moves. 46% of moves in this warehouse are Fluofix moves, which is around 276 monthly moves. Around 60% of moves match with the 10 chosen SKUs, which equates to 166 moves per month with a gain per move of 2:04 min, or 5.7 hours/month (or 343.1 min/month), equivalent to 0.032 FTE.

4.1.1.1 Routing algorithm

As mentioned before, the routing algorithm parameter was changed from higher stock to alphabetical order, as the higher stock location parameter would disregard the dedicated locations since the

coding doesn't support this type of priority. This change doesn't affect any other sub-warehouse in a significant way apart from Central. With this change, although the alphabetical order also doesn't support dedicated locations, as long as the SKUs are located in the first few racks of the A row, Figure 4.5, they will be prioritized.

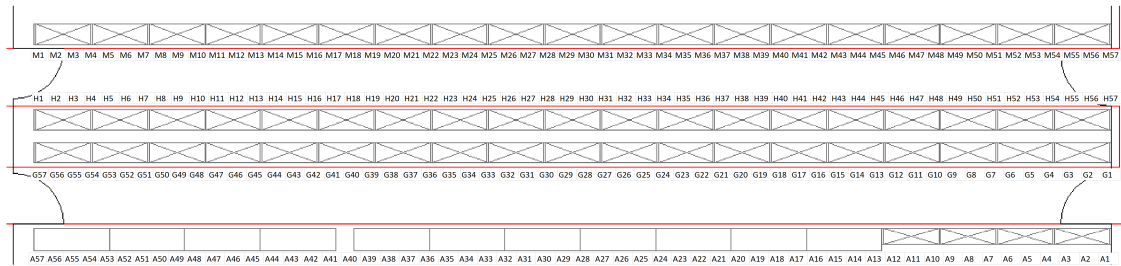


Figure 4.5: Central layout with storage locations

Although this change was positive and required for locating items based on affinity, it is still problematic and has a lot of room for improvement right off the bat. The main problem with this parameter lies in the fact that the alphabetical order followed is A1-A57-G1-G57-H1-H57-M1-M57 and the locations are not consistent from right to left in both corridors. In extreme cases, if a Fluofix item is located in A57 and M57, and the optimal route would be to take the item in M57 and then go into Secondary for delivery, the alphabetical order will assign the worker to the A57 location, on the opposite edge of the warehouse which in turn also forces a long walk back, up to 5 times more distance travelled in extreme cases such as in Figure 4.6.

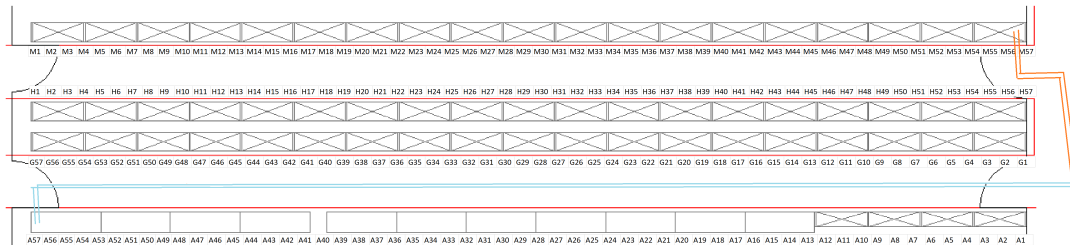


Figure 4.6: Blue: Route to A57; Orange: Route to M57

On one hand, one improvement measure that should be considered is altering location identification (with all WMS implications of swapping SKUs from one location to the other) to have a more consistent and organized warehouse, which leads to less confusion for workers as well as being more accessible for further routing algorithm implementations. This ties in with another improvement measure that enables a lot more flexibility and optimized routing by creating a new algorithm that can support dedicated storage locations as well as prioritize locations in a more customizable order for each product family.

Fluofix picking orders would benefit from an algorithm that chooses item locations close to the right side of Central, as after picking items there, the passage significantly closer to the Fluofix production line is on the right side and would ideally deliver the cart through there. It should also

support this product's dedicated storage locations. Normafix orders would be similar to Fluofix, with a bigger emphasis on the right side passage, being that its production line is on the top right area of Secondary. For Normacel, as the production line extends throughout Primary, the algorithm should shorten the distance travelled by the worker between locations but with no emphasis on any particular side of the warehouse as both passages are located at similar distances from where the items would then be delivered. For Divac, as the production area is located on the left-end of Primary, considering there is no middle point passage between the two corridors, the algorithm should prioritize a route that incorporates the fact that the worker will need to traverse an entire corridor due to naturally using the left side passage into Primary. Overall, the main solution to this problem would be to develop an actual routing algorithm that takes into account each family's specificity and also minimize travelling distance.

Another solution with ease of implementation is to create a gap in the middle of Central with the width of a single rack. This would allow for an improvement in aisle traversal so that workers are not forced to go to either end. By adopting this, S-shape traversal would be an improvement especially for Fluofix and Normafix picking orders. Two case scenarios are presented in Figure 4.7 and 4.8, where in the first path workers must backtrack twice to access locations up to the middle point of the warehouse, and in the second path workers can traverse without backtracking. Assuming that items are located according to their preferred side (Fluofix and Normafix on the right side, the rest on the left side), opening up this passage point could lead to a decrease in travelling distance of up to 50%, in the limit case that the items to be picked are in the middle point locations. The main downside of this solution is that the Central warehouse would lose two racks-worth of storage locations from rows G and H, which can be a limiting factor that should be taken into account.

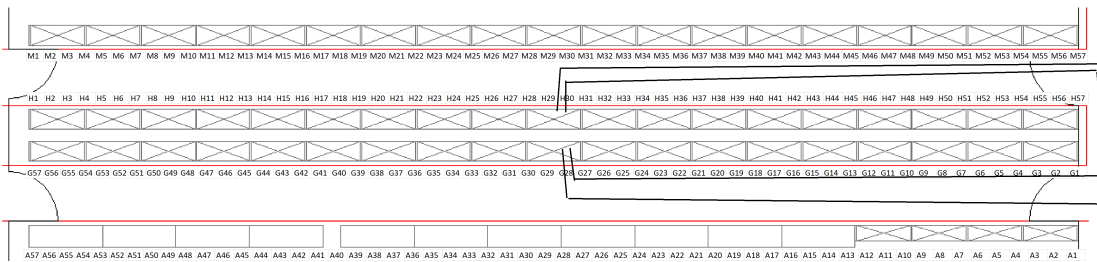


Figure 4.7: Current aisle traversal

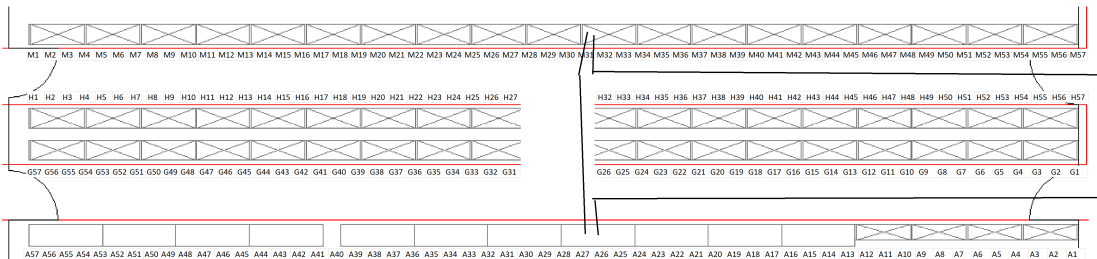


Figure 4.8: Possible aisle traversal with a middlepoint gap

4.1.2 Altering item storage locations based on demand

In warehouses where SKU variability is high and storage locations are limited, inventory analysis with a focus on demand is important so that high rotation items are located in optimal areas in order to facilitate and reduce time spent in order picking. Many times, obsolete and low demand parts can fill up locations that are desirable for high rotation SKUs. With this in mind, periodic stock demand analysis is key in order to ensure correct storage assignment and identify problematic SKU-location combinations that could've remained unnoticed.

When analyzing product variability, items are usually stored based on their dimensions. Larger products that come in large wood crates or semi-finished heavy parts are stored in Central, while smaller dimensional parts are stored throughout Supermarket1, Supermarket2 and Ulises. In Ulises in particular, SKUs are analyzed by higher up personnel which decide if they belong in the vertical towers due to either their small dimensions or their importance and monetary value for the case of more accurately tracking their stock and avoid generalized losses. Considering the previous limitations, Supermarket1 and Supermarket2 were analyzed due to the interchangeability of most SKUs and locations in terms of physical requirements and capacity. By retrieving data related to warehouse movements in the past 3 years from the WMS it was possible to analyze the demand of each SKU for the past 3 years as well as only 2022, and by cross-referencing this data with current location data, SKU demand was organized and divided by Supermarket1 and Supermarket2, splitting it into mezzanine and ground floor levels, as seen in Figures 4.9, 4.10 and 4.11.



Figure 4.9: Snippet of the Excel demand analysis for Supermarket1

SKUs Ground Floor Supermercado2

SKUs	Demand Total							SKUs	Demand 2022
33108201-	625							33108201-	173
33104351-	463							33104351-	132
331180383	420		%	SKUs	Demand	%		DI1501360	117
DI1501360	406	←←←←	100%	553	16727	100%		33110859-	97
35309004-	389	←←←←	20%	111	13353	80%		33102024-	96
EMT29444	344							33107470-	90
33107087-	282		100%	312	3576	100%	→→→→	33107471-	89
32204327-	255		20%	62	2774	78%	→→→→	33102061-	89
33106126-	206							33108006-	83
33102024-	205							331180383	79
33103067-	204							35309004-	77
33110859-	200							353160069	68
334120282	198							33105235-	57
33108006-	195							335190003	54
32216022-	195							331120749	54
34517122-	186							33110638-	54
33111884-	182							33110634-	54
353160069	178							33110630-	54
33102061-	173							33109174-	54
33107470-	173							331120599	53
33107471-	172							331120598	53
EMT49511	169							331120597	53
33111931-	163							33107246-	53

Figure 4.10: Snippet of the Excel demand analysis for ground floor levels of Supermarket2

SKUs Mezzanine Supermercado2

SKUs	Demand Total							SKUs	Demand 2022
32803247-	415							DI1501245	99
37303017-	323							33103067-	91
33103067-	283		%	SKUs	Demand	%		33116145-	60
DI1501245	196	←←←←	100%	92	3518	100%		33111037-	60
322120245	196	←←←←	20%	19	2711	77%		33102064-	55
33102064-	177							33111037-	50
33116145-	161		100%	61	782	100%	→→→→	37303017-	48
33111037-	121		20%	12	592	76%	→→→→	322120245	41
33111037-	121							37303017-	30
35316164-	106							37150650-	22
32807105-	95							33103067-	18
37303017-	80							BMT69623	18
34517122-	78							32803247-	16
32807110-	77							34517122-	11
334150076	59							22356463-	10
BMT69623	57							334150076	10
34517122-	56							DMTC9832	10
36510204-	56							32807110-	8
37150650-	54							37150143-	7
EMT49649	47							34517122-	7
33103067-	46							35316164-	7
32803220-	40							32805069-	7
34517122-	35							31215115-	6

Figure 4.11: Snippet of the Excel demand analysis for mezzanine levels of Supermarket2

In order to streamline the analysis, the Pareto Principle, often referred to as the 80/20 Rule, was followed. This method suggests that 80% of the demand corresponds to 20% of the SKUs,

which was verified for each of the sub-warehouses. As verified previously, Mezzanine levels in Supermarket2 represent a significant time increase relative to ground floor levels and Supermarket1, therefore the primary focus was to check whether SKUs located in the mezzanine could be swapped for others. The top 20% most demanded items were selected, equivalent to 19 when considering the 3 year time frame, and their demand was compared to the demand of the least requested SKUs of Supermarket 1, as this swap, if possible, would result in a greater time reduction compared to ground floor levels of Supermarket2. When analyzing this data, there are over 500 items with no WMS movements registered in the past 3 years of the over 1100 items located in Supermarket 1, therefore in the event that there aren't enough locations to fit 19 SKUs, these should be swapped for the ones with no demand.

Taking into account the time per SKU attributed to each different location in table 5.1, future predictions estimate that there would be 2400 movements a month in Supermarket2, 17.4% of which are in the mezzanine levels according to historical data proportions, 418 a month. Assuming that 80% of these match the top 20% of SKUs selected before (19), 334 movements would have a time improvement of 45%, 1:05min less per SKU, an overall gain of 6 hours per month, equivalent to 0.034 FTE.

Using the same line of thought as the previous assessment, ground floor level SKUs in Supermarket2 were analyzed for the possibility of relocating them to Supermarket1 under the assumption that this would reduce time spent per SKU from 1:43 to 1:20, an improvement of 22%, or 23 seconds of additional time per SKU. Considering this, under the Pareto Principle, 111 SKUs were selected which ultimately resulted in the equivalent to 1388 movements a month with a time save. This adds up to 8.87 hours or 8 hours 52 minutes, however on a time gain per SKU moved, this is 4 times lower than when moving items from the mezzanine locations. In order to draw comparisons between the two measures, Table 4.5 was drawn, including the assumption that each and any SKU would take 30 minutes on average to be relocated regardless of location for calculating Time to Benefit purposes:

Table 4.5: Time gain and time to benefit comparison for relocating SKUs

Initial	Final	Qty. of SKUs	Total Time Gain (h/month)	Time to Benefit (months)
S.2 Mezzanine	S.1	19	6.00	1.58
S.2 Ground Floor	S.1	111	8.87	6.26

4.2 Reducing Stock Difference Errors

One of the main goals of this project was to understand what the root causes of stock differences were between the digital management systems, WMS and ERP, as well as between WMS and what's physically present in the unit. Firstly, starting with the WMS vs ERP problem, as previously mentioned in Chapter 3, the WMS has a section dedicated to comparing the digital system discrepancies and quantifying them, as seen in Figure 4.12, where data regarding cost and quantity of each SKU can be seen. As helpful as this display of information is, it is limited in the way in

which these stock differences can be tracked in a timeline in order to understand when and why a certain error occurred. With this limitation in mind, an Excel tool was developed in order to track errors. This tool requires inputting data sheets directly extracted from the WMS errors tab from two different points in time. In these data sheets, as seen in Figure 4.12, "Qt. Atlas" refers to the stock quantity registered in WMS, "Qt. ERP" refers to the stock quantity registered in ERP and Atlas-ERP is the difference between these two. During this analysis, error lists had approximately 4500 SKUs in each.

Artigo	Descrição	Qt. Atlas	Qt. ERP	Qt. CA	Atlas-ERP	KB max.	Atlas Res.	Un.Eur	Tot.Eur	Ult.mov.	Armazém
100109002	TUBO METALICO FLEX. PG16-M20	1701.10	2139.25	0.00	-438.15	16.00	0.00	1.85	-810.58		182024
1005902	TUBO METALICO FLEXIVEL D12	233.00	30.77	0.00	202.23	16.00	0.00	1.54	311.44		182024
1005908	TUBO METALICO REV. FLEX. PG21	467.55	442.55	0.00	25.00	0.00	0.00	1.50	37.50		182024
1005989	A+PVC TUBO FLEXIVEL D 23	370.00	25.00	0.00	345.00	0.00	0.00	1.50	517.50		182024
1006912	ALM PERF CHAPEU 35X 7,5 ZN NP	0.00	50.40	0.00	-50.40	0.00	0.00	0.00	-0.01		182024

Figure 4.12: Snippet of the data sheet extracted from WMS

Next, the tool requires the user to input the names of the two Excel sheets in the two cells designated for the effect, seen in Figure Y as "Dia atual" and "Dia anterior" (meaning "Current Date" and "Previous date", in this case the Excel sheets were called "5dez" and "25nov"). Then, at the click of the button "Juntar Listas", a macro runs which combines data from both sheets into a single list with all the previous information related to quantity in WMS and ERP and cost for each SKU in these data sets.

Artigo	Descrição	Atlas 5dez	Atlas 25nov	Δ Atlas	ERP 5dez	ERP 25nov	Δ ERP	Atlas-ERP 5dez	Atlas-ERP 25nov	Δ Atlas-ERP	Origem de dados	Classificação prioridade	Observação	Responsável	Dia atual	Dia anterior
32216044	ANILHA DE CONTACTO	0.00	Sem info	Sem info	1754.00	Sem info	Sem info	1754.00	0	0	#VALOR!	-	1		5dez	25nov
1211140005	REBITE C/ ANELO 5x04	0.00	Sem info	Sem info	500.00	Sem info	Sem info	500.00	0	0	#VALOR!	-	1			
23341957	PORCA AIN M10H A4-80 ISO4032	356.00	Sem info	Sem info	0.00	Sem info	Sem info	356.00	0	0	#VALOR!	-	1			
32216010-01	INOLA COMPRESSAO	4397.00	Sem info	Sem info	4097.00	Sem info	Sem info	500.00	0	0	#VALOR!	-	1			
MIT060170-01	ETIQUETA PVC PARA SINALIZADOR	214.00	Sem info	Sem info	0.00	Sem info	Sem info	214.00	0	0	#VALOR!	-	1			
9910043	CABO UICY 2X1.5 MM2 CINZA	0.00	Sem info	Sem info	205.00	Sem info	Sem info	205.00	0	0	#VALOR!	-	1			
600018F157	PF H M16x25-8.8 ZN40H ISO4017	192.00	Sem info	Sem info	0.00	Sem info	Sem info	192.00	0	0	#VALOR!	-	1			
EMT396420-01	ANILHA CALCO	149.00	Sem info	Sem info	0.00	Sem info	Sem info	149.00	0	0	#VALOR!	-	1			

Figure 4.13: Snippet of the categorization sheet for a given time frame

At the same time, each SKU is categorized into one of the following designations: a New Error (indicated by a 1), which is an error that should be given higher priority for investigation because it means that an error has originated between the first timestamp and the second, a Preexisting Error with a Variation (indicated by a 2), which is an error that was already present in the first data set but has suffered a variation in the stock quantity difference between the two systems and required a medium priority level as these would usually be harder to investigate and the cause was much more complex to pinpoint, a Preexisting Error with no Variation (indicated by a 3), which is an

error that was present in the first data set but has suffered no more stock difference variation and as such is given a lower priority as it makes them increasingly harder to accurately track through movement records. Apart from this, the same philosophy of designations was used for Kanban SKUs, however in this case, as Kanban storage is only tracked in ranges of half a box's worth of stock, further implementations were made to correctly classify them according to each different SKU's box quantity with the aid of information from the Kanban storage system. If a new error between WMS and ERP for a Kanban SKU was below the equivalent stock of half a box, it would not be considered a New Error Kanban, it would be classified as No Error Kanban. Once the lists are combined, the user can press the "Sort" button to automatically sort the errors in the predefined priority order. This is seen on the column named "Classificação/prioridade desvio".

Initially, with the assistance of this new tool, data was extracted and compared on a daily basis in an effort to identify error occurrence immediately. Once a New Error was identified, the SKU in question and its respective stock difference were analyzed closely by tracing back the entries on both the WMS and ERP and identifying its origin. After multiple weeks of data gathering, these errors were typified and divided into the root causes in Table 4.6. In addition to this, short and long term solutions to reduce the occurrence of these errors have been addressed.

It is important to note that these causes are primarily related to regular daily activity, where due to the systems lack of synchrony, difference errors occur. The main issue is that when these differences are not accounted for and adjusted correctly, they tend to accumulate over time, leading to increasingly complex and difficult to trace discrepancies. In the case of the error "Reverting ERP consumption without physical return", for example, production orders are reverted but production workers often disregard the importance of physically returning what they assume are minor items or keep them in the eventuality that they are needed for a following production order and end up stacking them on their workplaces. From gemba walks and conversation with workers, often they encountered defective or excessive items which were not required for assembly but did not physically return the item for storing. From a technological standpoint, improving the WMS-ERP interaction is a must in order to mitigate these issues and to track stocks with increased certainty.

If the previous considerations are taken into account, these issues are expected to mostly subside. Another important part of eliminating these issues is related to Inventory Count, which is realistically the only method of fixing already existing differences by physically counting all of the stock inside the warehouse and then adjusting every SKU accordingly. During the time frame of this project, there was an ongoing inventory count to adjust the preexisting stock differences. During this period of time, some of the New Errors found through the Excel tool were related to WMS entries which hadn't been adjusted yet as it would only happen once the inventory count as a whole was concluded. This introduced some noise to the data gathering process but was successfully mitigated.

It should be noted that a portion of the "Preexisting Error with no Variation" issues are related to items which are only tracked in ERP and not in WMS, which means that they are not actual errors. To counteract this, filtering options should be added to this Atlas tab, in order to visualize errors in a more organized and consistent way.

Table 4.6: Error typing and solutions

Root Cause	Description	Short Term Solutions	Long Term Solutions
Missing receiving	An order is physically received and registered on the WMS but there is no entry on the ERP.	Instructing workers on the importance of completing receiving orders with no interruptions or delays to avoid discrepancy.	Develop system integration in order to synchronize WMS and ERP to be able to create both entries at the same time instead of sequentially.
Reverting ERP consumption without physical return	SKU consumption from production orders is reverted by production workers when excess items are encountered or orders are cancelled and need to be returned to their storage locations.	Instructing the planning team not to revert ERP consumption without notifying the logistics team. Creating defined locations for returning material to the warehouse.	Developing the WMS to enable reverting order consumption through WMS instead of ERP when items physically arrive at the warehouse for storing. Review the process of altering material lists while production orders are active which cause materials to be stuck in production lines.
Physical return of items without reverting ERP consumption	Items are sent back to the warehouse without reentering the ERP system.	The logistics team should enter items in the ERP at the same time that items physically arrive at the warehouse and are entered in the WMS.	Increasing WMS capabilities to identify items returning from production lines by differentiating them from inbound orders. When the item enters the WMS, the ERP order is reverted.
ERP consumption without WMS movement	When a picking order is started, items are all consumed from the ERP before they are individually consumed or moved in the WMS, due to system synchrony limitations.	Instructing order picking workers to finish picking all items on the same day that the production order is initiated.	Synchronize WMS and ERP to allow for items to only be consumed one by one during the picking order.

For the future, it is proposed that the business unit continues to make use of the Excel tool or its equivalent implementation into the WMS in order to continually track new occurrences so that they can be addressed in a timely manner.

On the topic of differences between the WMS and the physical system, and consequently the ERP, as previously mentioned, manual inventory count is the preferred method to ensure that information is up to date. The full inventory count efforts were concluded in the timeline of the project and from over 4500 SKUs with uncertainty, only less than 1200 were still showing up on the WMS difference tab. The degree of success of this method was significant however the process is very demanding in terms of labor, as workers need to verify and count every single location and

SKU on the whole unit, taking time away from other functions in part due to having to leave their workplaces and be put to par on the status of the count. In the specific case of Efacec's low activity level, it wasn't as much of an issue, however if activity level is high workers can't be exclusively dealing with inventory counts.

Considering this, it is proposed that a new method of inventory count based on continuous stock checking should be implemented. In this proposal, during a picking order, workers are alerted by the WMS based on defined criteria, such as when the stock in a location reaches an easily countable arbitrary amount, for example 5, so that while fulfilling the order they also aid in inventory count seamlessly and with little effort. This would allow for popular SKUs to be counted on a semi-regular basis, which are more prone to have stock deviations due to higher movement counts. This shouldn't exclude total inventory counts, however more up to date information is expected to help alleviate time expended by workers in these efforts.

4.3 Improving the delivery method

The third goal defined at the start of the project was to improve the procedure of delivering items to improve the follow-up work. The focus of this analysis started with the Divac production line, as from the information that was gathered from workers and higher-ups, as seen in the "Current State" chapter, production line crew had to sort and separate the items once they arrived, meaning there was no previous effort in organizing the materials to eliminate this time waste. This is due to the fact that production orders entered in the ERP grouped multiple Divac products into a single order with no distinction of materials for each Divac, and the same happened for the WMS as you could only have one picking order per ERP production order.

Firstly, to determine the time spent on sorting and dividing items, a partial picking order of 5 Divac products was accompanied where only smaller dimension items were picked, as larger dimension items are easily distinguishable and production workers do not waste time on retrieving those. These smaller dimension items were all available in the Ulises system, Supermarket1 and Supermarket2, for which the time per SKU picked was previously determined in Table 4.1. Using these values and the quantity of SKUs it was possible to calculate the expected time on solely picking the items without separating them into 5 individual kits for assembly. After gathering all the items, the separation in kits was timed through a stopwatch while a worker arranged each one in a plastic crate fit for delivery. The average of time per Divac was calculated resulting in 5 minutes and 26 seconds. For an order of N Divac products, the resulting total time to separate is (N-1) times that, due to the fact that the last group of items available is separated when sorting the penultimate kit.

Using the case example of 5 Divac products in an order again, three scenarios were considered as presented in Table 4.7: first, the current method, where the ERP order and the WMS order are both grouped and items can't be separated, forcing production crew to spend time separating materials. This also makes tracking orders in the event of a problem occurring harder due to the increased number of items in a single order instead of 5 separate orders; second, each production

order is separate, which in turns means that each picking order is also separate. This can be immediately implemented without system development concerns, makes organizing and tracking orders simpler, but has the downside of turning an otherwise batch picking procedure into a discrete picking procedure unnecessarily, leading to an increase in picking time of up to 5 times, considering an approximately equal time to gather each SKU; third, production orders should be separate, while the WMS should be developed in order to account for batch picking procedures, that is, a single picking order can distinguish items for multiple single Divac products, while still grouping them in order to have a low overall picking time. In this case, order picking workers would separate the items immediately into plastic crates according to WMS instructions, which isn't expected to add any significant time to their side of the process. Considering the total times from scenario 1 and 3, there is a time decrease of 34%, 21 minutes and 44 seconds for a 5 Divac picking order and therefore is the improvement proposal for this particular problem.

Table 4.7: Scenario comparison for Divac delivery

Scenario	Time by pickers	Time by production workers	Total time
1	41 min 41 s	21 min 44 s	1 h 3 min 25 s
2	3 h 28 min 25 s	0	3 h 28 min 25 s
3	41 min 41 s	0	41 min 41 s

Apart from this, it was also relevant to understand what could be improved in terms of how items can be arranged in the delivery tool, as in the batch picking proposal, similar to the initial situation, there was no organization or separation of items apart from the plastic crates. There is also no ordering on how they are arranged which, if done correctly, is expected to make the follow-up work by production crew more intuitive and efficient. Considering this, one proposal is to switch from using a pallet for order delivery to a multi-level picking cart similar to the ones used for Fluofix or Normafix, where each level can fit a Divac kit. This helps to physically separate items belonging to each kit instead of the one pallet configuration. Another proposal is to use two or more plastic crates for each kit in order to separate items which are used in different stages of Divac assembly. By assigning the stages to them items through WMS, pickers can correctly sort the items into crates which allows production workers to know what group of items they should grab first for assembly and so on. This is expected to aid in production while adding little to no extra time to the picking process.

Chapter 5

Conclusions and future work

This project consisted in evaluating the current state of processes in Efacec's AMT Switchgear and propose measures to improve them which was possible across the three defined objectives. It is worth noting that during this project, Efacec is facing financial strain due to external factors. This can serve as a double-edged sword, if on one hand this leads to a lower activity level and therefore less available data for analysis due to the aforementioned constraint, on the other hand the slower pace can prove useful in more thoroughly understanding the processes and the ways in which they can be improved.

The proposed measures consisted of:

- Altering storage location of 10 SKUs in Central based on affinity, with a gain of 5.7 hours/-month, equivalent to 0.032 FTE;
- Routing algorithm development for overall increased efficiency, and opening a traversal point between two aisles in Central to allow for picking distance reduction of up to 50% in common cases;
- Altering storage location of 19 SKUs in Supermarket2 Mezzanine based on demand, with a gain of 6 hours/month, equivalent to 0.034 FTE;
- Implementing a tool created during the project to more accurately track stock difference errors;
- Implement short term and long term measures to mitigate each type of stock difference error encountered;
- Implement a new inventory count policy based on WMS instructions in the midst of picking orders to ensure continuous and seamless stock tracking;
- Defined new delivery procedures for the Divac production line, with an estimated time reduction of 34% per production order.

Some of these could not be accurately estimated in FTE, but are were still considered significantly beneficial. Of these proposed measures, only the first, forth and fifth (partially) were

implemented by the end of the project's duration. This is due to the time and effort required for the implementation of some of these measures, but also due to WMS and financial limitations. The results from measures related to stock difference errors could not realistically be estimated in quantifiable terms nor measured in the small time frame of the project but is expected to be significantly beneficial. Future implementation of the previously mentioned measures should be closely monitored in order to confirm the expected results and to evaluate the success of the measures with qualitatively estimated outcomes. The resulting time saves, better tracking and improved delivery procedures are expected to raise Efacec's throughput in the event of increased production. Furthermore, commenting on the delivery procedures, the batch picking method used in the Divac production line could still be explored regarding other production lines as it shows great potential for decreasing time per picking order if the conditions required can be met, such as product variability and possibility of delivering in batches in regards to keeping up production with deliveries in less frequent intervals.

One of the main adversities encountered throughout this project had to do with the fact that the Atlas WMS used by the unit could not be easily adapted in time to adopt newer ideas which limited the practical implementation of some improvement measures, leading to band-aid solutions such as the dedicated storage being forced to be in the initial A row locations. While these type of measures can be followed through from a management philosophy standpoint, their current practical application (dedicated storage being in A row) should cease once the WMS is further developed and accounts for them regardless of the previous restrictions (dedicated storage being in any row, as defined by management).

In regards to future work, it is suggested that Efacec explores technological improvements in the realm of Industry 4.0, such as Digital Twin or Virtual Reality applications for the ability to simulate the factory unit environment and more accurately evaluate areas of improvement and potential gain of proposed measures. Other practical applications such as Pick-By-Light and Pick-By-Voice can be explored as methods of improving picking efficiency. RFID can be investigated as a possibility for both inventory tracking applications and picking cart availability tracking.

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Appendix A

AMT layout

