Improvement of the shipping process in a semiconductor industry using Lean methodology

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Abstract

The semiconductor industry is increasingly associated with perfection. The small margins needed to make the business flourish and the demanding technical specifications related to mass production of these small units, allied with the ever-growing need for this type of technology, place this industry in a very competitive environment.

This work aims to analyze and improve the fundamental processes in the shipping area at ATEP, which is known to house several activities that have the potential for improvement.

For this process analysis, several methodologies such as Lean thinking and time and motion study were applied to understand which activities had the potential to be improved in the shipping process and measure the impacts proposed and implemented solutions would have.

The layout of the shipping area was changed according to requirements defined by the factory's production plan, operators' movements and material consumption, which resulted in a more capable and efficient location to absorb the increase in product references and client portfolio.

These changes also contemplated two types of equipment that reduced the risk of the operator contracting a musculoskeletal disorder, contributing to the workstation's ergonomic and human factors improvement.

Finally, several tasks involving weighing and lot distribution activities were automated, removing identified wastes and increasing the packing process efficiency. This resulted in over 65.62 hours of annual labour being saved in 2021 and 82.28 hours in 2022.

Resumo

A indústria de semicondutores está cada vez mais relacionada com a perfeição. As pequenas margens que garantem o sucesso e as difíceis especificações técnicas ligadas à produção em massa destas pequenas unidades, aliadas com o constante aumento da sua procura faz com que esta indústria esteja num mercado muito competitivo.

Este estudo tem como objetivo de analisar e propor melhorias ao processo logístico na área de expedição da ATEP, que contém diversas atividades com potencial de melhoria.

Metodologias como o pensamento Lean e o estudo dos métodos e tempos foram aplicados na análise do processo, para compreender quais as atividades com potencial para serem melhoradas e medir os seus impactos.

O *layout* da área de expedição foi alterado de acordo com os requisitos definidos pelo plano de produção da fábrica, movimento dos operadores e consumo de materiais, tornando esta zona capaz de operar eficientemente com o aumento de referencias de produtos e número de clientes.

As mudanças nesta área também incluem a consideração de dois novos tipos de equipamentos capazes de reduzir o risco de os operadores contraírem distúrbios ósseos, articulares e musculares, contribuindo, desta forma, para uma melhoria ergonómica do local de trabalho.

Por fim, a automação de várias atividades relacionadas com a pesagem e distribuição de lotes permitiu remover desperdícios e aumentar a eficiência do processo de expedição, com a redução de um total de 65.62 horas de mão de obra anuais em 2021, e 82.28 horas em 2022.

Acknowledgements

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Last but not least, I would like to thank my parents, which taught me that with perseverance and hard work, anything is possible.

"Strive for perfection in everything you do. Take the best that exists and make it better. When it does not exist, design it."

Sir Henry Royce

Contents

Acronyms and Symbols

ATEP	Amkor Technology Europe Portugal
CPI	Continual process improvement
ESD	Eletrostatic Discharge
FOSB	Front Opening Shipping Box
HWS	Horizontal Wafer Shipper
e.g.	*exempli gratia*
IC	Integrated Circuit
i.e.	*id est*
IE	Industrial Engineering
ILP	Integer Linear Programming
LP	Linear Programming
MFS	Multiframe shipper
MTO	Make to order
MSD	Musculoskeletal disorder
OWAS	Ovako Working Posture Analysing System
PDCA	Plan-do-check-act
ROA	Return on Assets
ROI	Return on investments
TB	Tray box
TPS	Toyota Production System
TR	Tape & Reel
TQM	Total Quality Management
REBA	Rapid Entire Body Assessment
RULA	Rapid Upper Limb Assessment

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Chapter 1

Introduction

The present work is the main project in the Dissertation Curricular Unit that concludes the Master's Degree in Mechanical Engineering at Faculdade de Engenharia da Universidade do Porto. This project was proposed by ATEP to improve the logistics process in the shipping area by proposing well-reasoned improvements.

This industry belongs to a very competitive and constantly changing market, where success is a matter of whom can produce more, has the most significant investment in research and development and the best logistics performance. This last part is crucial to ATEP since most of their clients and suppliers are located in the Southeast Asian continent. To be relevant, they need to handle the transactions very efficiently.

The semiconductor industry's growth is reflected in the company's extension of product types and client portfolio, resulting in increased references, packing sub-processes, and pressure on the company's logistic resources.

1.1 Framework and Motivation

This logistics process improvement project of ATEP's expedition area is part of the Logistics and Planning department (Planeamento e Logistica - P.L.). This is one of the seven departments at ATEP. It is divided into two parts: The Planning team, which is responsible for the raw materials and important components purchasing and production planning, and the Logistics team, which handles the expedition of the final product to the clients, and manages the factory's raw material, spare parts and general products needs, but also is in charge of supervising the warehouses and shipping area. In Figure 1.1 it is possible to observe all other departments at ATEP.

This study will dwell on the expedition process of the final products to the clients, as it is the area with the most potential for improvement and with the most known efficiency problems.

ATEP puts much emphasis, as one should, on the Total Quality Management (TQM) principles and Lean manufacturing developed by Taiichi Ohno. One of these principles is an excellent Customer Service experience, making this area a critical one to the logistics department since it is the only "physical" contact ATEP has with its clients. This part of the process is essential due

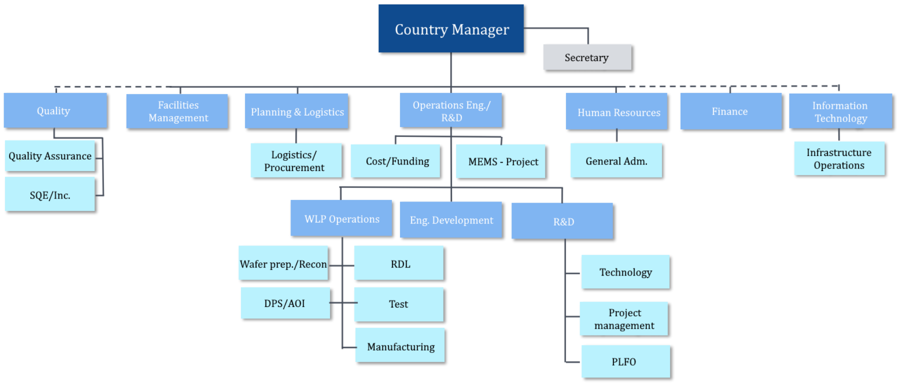

Figure 1.1: ATEP's departments

to the "Zero Defects" mindset followed by the company; any error made will deteriorate its client relationship. In other words, all customer specifications must be met in the shortest time possible since the material that comes from production is not the only product shipped by the company. Given the department's demands, it is mandatory that all the processes are well-defined and automated to the maximum to reduce the probability of human error and improve process efficiency. So that it has enough flexibility to support an increase in production and product diversity without compromising the customer relationship.

1.2 Semiconductors and its Market

A *semiconductor material* can be defined as a material that has the electrical conductivity between a conductor (such as metallic copper) and an insulator (such as glass). Its resistivity is a function of its temperature - when the temperature rises, its resistivity falls, allowing electricity to pass through[1].

Its conducting properties may be altered by adding impurities (known as *"doping"*) to the Crystal Structure. The differently doped regions present in the same crystal form a Semiconductor Junction. The behaviour of charge carriers at these junctions is the basis of diodes, transistors and most modern electronics. Most semiconductors are obtained from an ingot of monocrystalline silicon, which the majority of the world's production has been mainly in China and Russia, and from front-end factories. (MicroChemicals, 2022)

It is possible to produce the components present in an Integrated Circuit needed to fabricate electronic devices such as *Smartphones* or automotive sensors from these materials and through several chemical and physical processes.

If we look around us, it is easy to perceive that electronics play a major role in our lives, and semiconductors are the core of these electronics, allowing the production of advanced equipment ranging from microwaves and refrigerators to solar cells. (Madan and Shaw, 2012)

[1]Metals behave the opposite way

The global semiconductor industry sales totalled US$555.9 billion (€521.35 billion) in 2021, the highest-ever annual total for this industry, and an increase of 26.2% compared with 2020 (US$440.4 billion or €413.03 billion), being sold 1.15 trillion semiconductors worldwide in 2021. Figure 1.2 identifies the decrease and consequent increase in the compiled worldwide revenue. This is a compilation of the monthly sales by the World Semiconductor Trade Statistics (WSTS) organization and represents a three-month moving average. (Ravi, 2022)

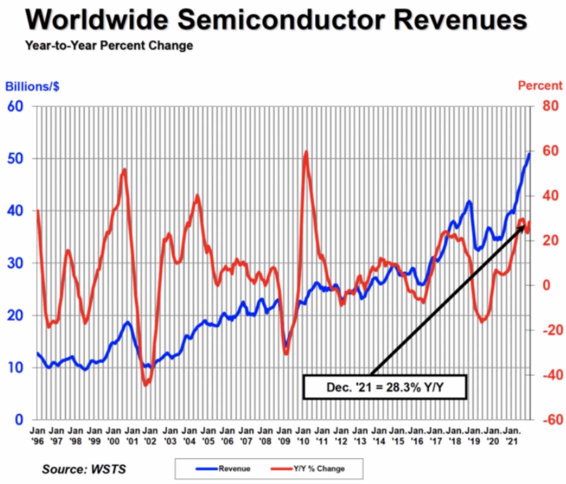

Figure 1.2: Worldwide Semiconductor Revenues per quarter.(Ravi, 2022)

The semiconductor industry is still recovering from the global shortage that began in the COVID-19 pandemic's early months when auto sales plummeted as much as 80% in Europe, 70 % in China and nearly 50 % in the U.S. The lack of demand for new vehicles shuttered auto factories while orders for semiconductors used in digital speedometers and navigation displays, for example, dropped off precipitously.

The effects of the semiconductor shortage have extended beyond the auto sector since automotive companies lost their market share to the significant increase in consumer demand for personal computers, servers and other equipment. When the auto sector recovered faster than anticipated, the semiconductor industry had already shifted production to meet the demand for other applications and could not absorb this demand increase. Geopolitical tensions, contract terms for the automotive industry, limited stock and the 5G rollout have also contributed to this market imbalance. (Burkacky et al., 2021)

The industry is now trying to recover with the increase in production capacity. However, according to Burkacky et al. (2021) there is no indication that this imbalance will be resolved in the short term because of the typically long lead times for semiconductor production, which can exceed the four months mark. Switching to a different manufacturer typically adds another year because of the chip design alterations. (Burkacky et al., 2021)

All these factors and events contribute to higher pressure in the whole industry, especially in the logistics departments, to meet customer demands.

1.3 Amkor Technology, Inc Group

Amkor Technology, Inc. is a publicly-traded company founded in 1968 that provides high-quality semiconductor design, assembly and test services. These two processes correspond to two of the three steps needed to produce a finished Integrated Circuit, ready for use in a host of electronic applications. The company also offers value-added services, such as electrical and thermal package characterization, helping designers learn how a device will perform in a finished package.

In 2021, Amkor presented net sales of US$ 6.1 billion and a share of 18.9% in the third quarter of the same year, maintaining its position as the second biggest player in the Outsourced Semiconductor Assembly and Test (OSAT) global market. This company has over 30,000 employees and 11,000,000 square feet (1,021,933.44 m^2) of manufacturing space, spread across 19 assembly and test facilities in 11 countries. The locations of all Amkor sites are displayed in Figure 1.3.

Figure 1.3: Amkor worldwide presence (provided by ATEP.)

Amkor has a *QualityFIRST* culture that combines several mindsets that allow the company to deliver defect-free products and provide flawless service beyond customer expectations, obtained by having the same mindset across all departments and having the mission to be the global supplier of assembly and manufacturing services of test and innovative solutions for semiconductor companies, using advanced technology in collaboration with clients and other partners.

The ever-changing semiconductor industry forces this kind of company to invest significantly in Research and Development to create more cost-effective innovative solutions.

1.4 ATEP - Amkor Technology Portugal, S.A.

Amkor Technology Europe Portugal (ATEP) was created following the acquisition of NANIUM, S.A. by Amkor Technology, Inc. in 2017. NANIUM was one of the world leaders in producing semiconductors with Wafer Level Fan-Out (WLFO) technology, allowing Amkor to strengthen its market position, reduce costs and open a gateway to its European clients with this high-yield production method.

ATEP's facilities are located in Mindelo, Vila do Conde and were initially designed by Siemens Semiconductors in 1996. In 1999, the german company decided to do a spin-off of its semiconductors unit, giving birth to Infineon. In 2006, the factory became known as Qimonda, a split out of Infineon Technologies to form, at the time, the second largest DRAM company worldwide. Following the ever-struggling DRAM sector in 2008, Qimonda filed for bankruptcy, and the factory was transformed into NANIUM.

In 2017, Amkor Technology, Inc. acquired the only Qimonda factory that escaped bankruptcy, giving it "the financial and growth capability" of the American giants. Nowadays, ATEP has over 700 collaborators, 20,000 m^2 of Clean Room space and 36,900 m^2 of social and technical areas.

1.5 Project Scope and Limitations

The final goals to achieve by the end of this project will be the improvement of the shipping layout, making it capable of absorbing the increase in volume shipped and the increase in the number of different destinations, the improvement of Ergonomics and Human Factors in the working stations and present a list of minor improvements that increase packing process efficiency.

In addition, achieving these goals will accompany a benefits and costs analysis study. This study will be limited to the products and material types and the clients mentioned in Subsection 3.1.3. Also, this study does not aim to analyze and predict future expedition volumes. The Planning Department, responsible for informing all the other departments of what the production volume will look like, provided these forecasts. Finally, the improvements provided in this dissertation may be influenced by the company's vision and client requirements.

1.6 Project Methodology

This project followed the specific timeline presented in Figure 1.4. In the first week, the study started with a global understanding of the company's products and operations, the main clients, and their requirements. The following three weeks were dedicated to comprehending the company's logistics reality.

The third and fourth phases mark the starting point of the actual study. The third and fourth phases mark the beginning of the study itself. Phase three began in the fifth week and extended until week eleven, and phase four started a week later and ended in week fourteen. These phases happened simultaneously for six weeks because some inefficiencies could be identified while observing and measuring each procedure.

These milestones were achieved after all the information was gathered and all measurements were taken. The last step in this project was the study and development of improvement alternatives and the impact this study will have on the logistic process, ending with presenting the results obtained. These stages were controlled by weekly meetings with the company advisor and the department manager.

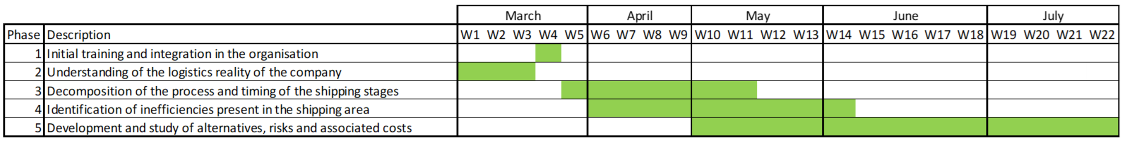

Figure 1.4: Project timeline.

1.7 Dissertation Structure

This dissertation begins with an introductory chapter that briefly explains the project, the semi-conductors State of the Art and the company where the study was done. Chapter 2 then exposes the theoretical concepts that served as the basis for this work.

Next, Chapter 3 explains the project itself and the current situation in detail. After this, in Chapter 4, the results and proposed improvements are exposed, and lastly, Chapter 5 gathers the main conclusions of this project.

Chapter 2

Literature Review

The purpose of this chapter is to present the theoretical concepts that served as a guideline for this project.

2.1 Lean Methodology

Lean methodology was considered to provide tools and mindsets essential to propose well-reasoned improvements throughout this project. The mindsets proposed helped guide the path taken in this study, while the tools allowed for a more concrete analysis of the considered processes.

Lean implementation can be described simply as the efficient utilisation of available resources. It is the real-world execution of Lean thinking, in the sense that Lean thinking provides a way of specifying value, planning value-creating actions in the best sequence, and performing them without interruption and upon request while operating increasingly more efficient. In a sense, Lean thinking is *lean* because it provides a way to add more value with increasingly fewer resources while improving customer service. (Womack and Jones, 1996)

This mentality provides "a way to make work more satisfying by providing immediate feedback" on these efforts. (Womack and Jones, 1996)

2.1.1 Toytota Production System (TPS) and 3 M's

Toyota developed the first ideas of this methodology. This giant automotive manufacturer developed it into a mature philosophy applied to all industries to improve all kinds of processes by removing non-value-added activities.

By the 1980s, it became clear to the rest of the world that Japanese quality and efficiency had something special, although it was why and how Toyota's cars lasted longer and needed less repair than American cars. By the 1990's it became apparent that there was something special about how Toyota engineered and manufactured autos that resulted in an unbelievable consistency in the production process and product, a faster project design process, yet at a competitive cost, even when paying relatively high wages. (Liker, 2004)

Nevertheless, what was the secret to Toyota's success? This incredible consistency is a direct result of operational excellence, based partly on tools and quality improvement mindsets developed by Toyota itself.

Toyota developed the TPS after World War II, as it had very different business conditions than the other big players in the automotive industry. Toyota's market was small, with various models in the same assembly line and customers to satisfy. This resulted in Toyota making a critical discovery: when production lines are forced to be flexible, and the effort is to cut lead times, the actual result is quality improvement, better customer responsiveness, better productivity, and better utilisation of equipment and space. (Liker, 2004)

"All we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value-added wastes." (Ohno and Bodek, 2019). Taichii Ohno defined, as Smith (2014) described, these non-value-added wastes as *muda*, and listed them as:

- **waiting**: waiting for materials, machines or workforce;
- **transporting**: excess movement of product from poor layout or overproduction;
- **processing**: including non-value-added steps in a process;
- **inventory**: inefficiencies in processes and queue times that create excess inventory;
- **motion**: poor work cell layout that does not regards ergonomics results in motion waste;
- **defects**: products that do not form, fit or function as the customer expected;
- **overproduction**: producing more than what is needed.

Nevertheless, *muda* is not the only waste that Taiichi Ohno realised was a problem. There was also *mura* (inconsistency) and *muri* (overburden), and all needed to be eliminated. As Womack (2006) suggested, the process of improving should not only analyse and eliminate one type of non-value-adding activities, but all three together: "The inevitable result is that *mura* creates *muri* that undercuts previous efforts to eliminate *muda*". (Smith, 2014)

2.1.2 Spaghetti diagrams

Various factors determine a company's success or failure in terms of competitiveness. These factors often relate to the product, the manufacturing process, and the people responsible for production. If the focus shifts to the operator as an essential factor affecting the production, making changes to optimise worker activities increases the potential for improvement by removing the already defined *wastes*. (Senderska et al., 2017)

As stated before, two of the wastes categorized as *muda* are **transporting** and **motion**, both referring to movement. One of the tools applied in lean implementations to remove these types of waste are *Spaghetti diagrams*.

A *spaghetti diagram* can be defined, according to Pyzdek (2021), as a visual tool that represents the physical movement of a "work object" through the processes in a value stream, and by analysing them, it is possible to identify non-value added movement that should be eliminated. This object could be a product, an employee, or a patient. As illustrated in Figure 2.1, a spaghetti diagram represents an object's or worker's movements in a system, represented by a line.

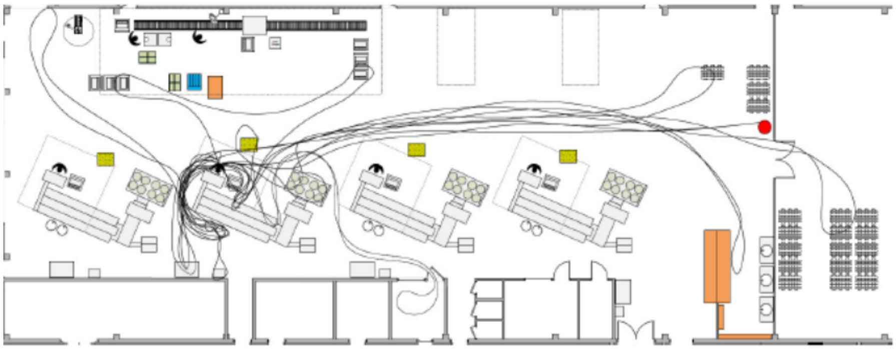

Figure 2.1: Example of a Spaghetti diagram. (Senderska et al., 2017)

Besides the visual representation, this analysis also gives the number and length of all the movements in a particular process, which is very useful when making changes to the process, material locations, or even to the actual layout in order to eliminate motion wastes as well as identifying inefficient movements or ineffective areas. (Senderska et al., 2017)

Creating a Spaghetti diagram

According to Daneshjo et al. (2021), these are the steps in creating these diagrams:

- Step 1: Analysis of the problem situation and setting the goal of the analysis
- Step 2: Elaboration of a production area scheme, determining the time and dimensions, material locations, and work positions
- Step 3: Definition and classification of movements
- Step 4: Creation and evaluation of the diagrams with the gathered data for both actual and variant layouts
- Step 5: Comparison of the results for each variant

Although this is the general process proposed in various articles, Pyzdek (2021) went further by saying that before elaborating a production area scheme, it is a must to understand where the value stream start and end points are for a better definition of the problem. After Step 2, it is also essential that the team and products are broken down into groups (or even individualised) for a better realisation of the actual situation. It is also essential that the studied object behaves like it usually should, i.e., the fact that the study is being done should not interfere with the results for them to be representative of the actual situation.

When measuring these movements, it can also be crucial to register unplanned stops and their reason, which may yield some conclusions that explain if it was a one-time event or reproduced several times. In addition, the line drawn on the map or the diagram that shows where the object travelled should not cross walls or be drawn over equipment or other barriers.

When analysing these charts, the improvement responsible should look for excessive number movements, insufficient movements, or even excessive travelled lengths. From a procedure standpoint, it is also interesting to analyse this data and determine if specific movements (not considered excessive or insufficient) are or not waste and determine if there is something that can be changed in the procedure that reduces these wastes.

There is an extensive range of options to gather data for creating these diagrams, from simple paper and pen to cellphone apps like *Spaghetti Diagram* on *Google Play*. However, the most commonly used is *Microsoft Excel*.

2.1.3 Plan-Do-Check-Act

The plan-do-check-act (PDCA) is a model for Continual process improvement (CPI). It teaches individuals and organisations to "plan an action, do it, check to see how it conforms with the plan and act on what has been learned". (Johnson, 2002)

According to Moen and Norman (2006), this model was re-designed from the Deming Wheel, established in 1951 by W. Edwards Deming, which modified an already well-known Shewart Cycle (1939). Deming changed the three-phase Shewart Cycle, stressing the importance of constant interaction between design, production, sales and research. Besides adding an extra step, Deming altered the existing steps to: Step 1 - Design the product; Step 2 - Make it and test it (in the production line and the laboratory); Step 3 - Put it on the market; Step 4 - Test it in service, through market research; Step 5 - Re-design the product. This evolution is pictured in Figure 2.2.

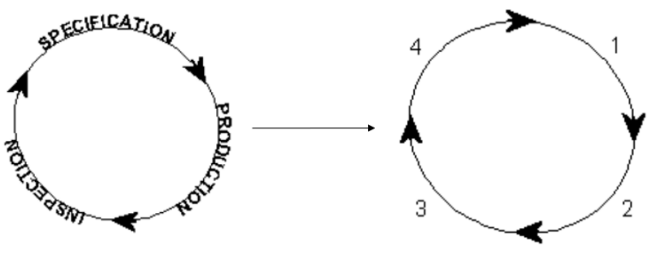

Figure 2.2: Evolution from the Shewart cycle (on the left) to the Deming wheel (on the right). (Moen and Norman, 2006)

Japanese executives later recast the Deming wheel after the 1950 JUSE seminar, creating the plan-do-check-act cycle, as shown in Figure 2.3. According to Moen and Norman (2006), Imai defined the correlation between the two, giving them broader meanings that can be applied to all types of management and not only production. These correlations are depicted next.

- Design - Plan: Product design corresponds to the planning phase of management;
- Production - Do: Production corresponds to doing-making, or working on the product that was designed;
- Sales - Check: Sales figures confirm whether the customer is satisfied;
- Sales - Check: In case of a complaint being filed, it has to be incorporated into the planning phase, and action taken for the next round of efforts.

By the 1960s, the PDCA cycle had evolved into an improvement cycle and a management tool in Japan. This method, allied with the Quality Control tools, became the foundation for improvement in Japan.

Figure 2.3: Japanese PDCA cycle. (Moen, 2009)

This method was used throughout this study to ensure the continuous improvement mindset in every action, change and process, even if it was not directly applied.

2.1.4 5S Philosophy

The 5S concept is a Japanese philosophy embedded in everyday life. The origin for the acronym are the Japanese words *seiri* (organization), *seiton* (neatless), *seiso* (cleaning), *seiketsu* (standardisation) and *shitsuke* (discipline). These terms are widely understood as a method for improving lifestyle, recognised as a group of organisational and cleaning activities that shape basic morality in everyday life. (Osada, 1989), (De Mente et al., 1994)

According to Kobayashi et al. (2008), this philosophy has been embedded in Japanese society by the culmination of several principles from Shintoism, Buddhism and Confucianism for several hundred years.

The first S, *seiri*, represents "organisation", meaning "put things in order, organising them". Distinguishing between the necessary and unnecessary to operate efficiently through a system. The second S, *seiton*, aims to have things in the right place so anyone can use/obtain them quickly. "Functional layout is also important: not only to maximise efficiency but also to improve quality." (Kobayashi et al., 2008)

The third one, *seiso*, means cleaning, emphasising self-inspection, cleanliness and the creation of a workplace without any faults. Actively inspecting machines by operators, embedding quality in each work, may guarantee a certain level of performance for a more extended period, for example.

The fourth S, *seiketsu*, means standardisation. As Osada interpreted, innovation and visual management improve the effectiveness of making things better for everyone. (Osada, 1989)

Lastly is *shitsuke*, which means training or discipline. "Pre-established behavioural patterns evolve naturally as a result of being guided by a philosophy, rather than just being dictated by upper management." (Kobayashi et al., 2008). To achieve goals efficiently and effectively, proactive changes must be made to people's behavioural patterns at all levels within an organisation.

5S philosophy was adopted in this study as a general mindset and guide to the improvements proposed, as will be mentioned in the following chapters.

2.2 Human factors and Ergonomics

As mentioned before, the success that Toyota saw with the implementation of certain mindsets transformed forever the way industries perceive and utilise their assets, and people being a vital intangible asset for a company, "it is imperative that they are measured and managed in a way that recognises their centrality" for the company's success. (Bassi and McMurrer, 2005), (Sveiby, 1997)

ATEP is no exception to this general movement happening across all industries, and it has been putting its efforts into implementing solutions to relieve the *stress* of collaborators may feel by the increase in pressure seen across this highly demanded industry.

2.2.1 Origin, goal and history

The fundamental principle that created the necessity for studying and understanding human and machine interactions is that "it is characteristic of human nature that we notice when things go wrong more easily than when things go right. Furthermore, it is the situation when things go wrong that triggers the call for diagnosis and solution "(Wickens et al., 2004). So ergonomics and human factors were born out of the need to overcome easy-to-relate obstacles.

The term ergonomics originates from the Latin word "Ergon", which means work. So the study of ergonomics and human factors aims to make human and machine interaction one where errors are reduced, productivity increased, and safety and comfort enhanced. These improvements often result in a more smooth and more efficient relationship between the operator and the operation, making the experience less stressful and fatiguing. (Wickens et al., 2004)

Ergonomics came about because the same historical process developments catalysed the appearance of industrial engineering and occupational medicine. The major works that served as the basis for this new subject were *Scientific Management*, by Taylor (2004), and *Workstudy*, by the Gillbreths, at the beginning of the twentieth century. Both were based on the "realisation that productivity could be improved by redesigning the way work was done". (Bridger, 2008)

At the time, management was only concerned with the productivity output, giving incentives to workers who suggested and provided improvements, and nobody was responsible for productivity, and the system was open to corruption. There were few formal ways of getting better systems or working procedures to ensure correct practices on a day-to-day basis. Taylor (2004) emphasised that it is the management's goal to manage, to have formal systems in place that "monitor working practices and their relationship to productivity" and to create an appropriate bonus scheme that maximised workers' output.

The problem this theory presents is the assumption that all parties in the industry can and do have the same interests. One of the best ways to maximise profits for shareholders is to minimise labour costs, which creates a conflict of interest for the company's management and collaborators. Around the same time, *Work study* was being developed by Frank and Lilian Gilbreth, which created methods for analysing and evaluating the way tasks were performed by breaking down single elements (movement and procedures) and allowing the inefficient and redundant ones to be eliminated, resulting in the redesigning and re-configuring the remaining elements to increase productivity. (Taylor, 2004)

The culmination of these two works gave companies a way to investigate and redesign tasks with human-machine interactions.

2.2.2 Musculoskeletal disorder prevention

Unfortunately, the overlook of this matter (by both the operator and the process planner) often results in a Musculoskeletal disorder (MSD). Hales and Bernard (1996) defines MSD as "disorders of the soft tissues and their surrounding structures not resulting from an acute or instantaneous event".

These disorders affect much of the workforce and remain a significant form of occupational ill health. Denis et al. (2008) defined the main risk factors for MSDs can be categorised as one of the four: force, posture, repetition and duration of risk.

Force is defined by the amount of effort a collaborator makes, in a particular direction, by applying a force in a single operation. Posture relates to a person's physical position maintained when standing or sitting. Repetition is the frequency in which the operation is done, and the risk duration is the time interval that a risk situation is maintained in a particular activity. The overall increase in these factors results in a higher risk of contracting an MSD, so reducing them results in a lower probability of harm.

Rethinking the design and process of these operations with these factors in mind allows for a more fluent workspace and better operator-equipment-product interaction.

2.2.3 Ergonomic intervention process

Denis et al. (2008) defined three steps of the *classical* ergonomic intervention process:

1. Preliminary analyses: defining the scope of the problems in the work situation;

2. Diagnosis: Finding causes (or determinants) for the identified problems, causes to which the changes or work situations should be directly related;

3. Solution-development: Solutions to change the work situation were developed.

In his study, Denis et al. (2008) stated that the most common variables used in the preliminary analyses were health indicators, workload-related activities and pain symptoms. Data collected is mainly done through documents and worker consultation. The diagnosis step can be carried out by establishing relationships between the content of the three major categories, namely the risk factors, the aspects of the work carried out, and the determinants of the risk factors.

The final step had three different approaches. The first method involved identifying a standard that would be directly applied to change the work situation. These standards were defined as the means to improve working conditions, like ergonomic guidelines and standards that governed the workload, among others. The second is to change the work situation by adapting existing standards, like partially modifying a design of a hand tool. The final approach consisted of developing a new design to change the work situation, and these were done where the problem could not be corrected with existing standards.

2.2.4 Risk assessment forms

To analyse and improve processes and tasks to reduce these types of disorders, companies could contract an independent company dealing with safety and health problems or hire a specialist. Although ideal, these two options require high amounts of financial effort. Most companies are now implementing risk assessment forms that allow a non-specialist in the matter to identify processes and tasks that represent a high risk of contracting an MSD.

These forms are considered observational techniques by Kee and Karwowski (2007) since the angular deviation of a body segment from the neutral position is obtained using visual perception. The instrument-based techniques continuously record body postures through a device attached to a person. As Kee and Karwowski (2007) pointed out, observational techniques are more widely used because of the low implementation cost.

These observational techniques include OWAS, REBA, and RULA, among others. The Ovako Working Posture Analysing System (OWAS) was developed by a Finish steel company that classifies combinations of four categories (back, arms, lower limbs and weight) by the degree of their impact. The result is then classified in terms of urgency.

The Rapid Upper Limb Assessment (RULA) technique was proposed to provide a quick assessment of the loading on the musculoskeletal system due to postures of the upper limb. Four action levels indicate the urgency of intervention required based on the grand score of its coding system. RULA is one of the most popular ergonomic assessment tools used in multiple industries because of the easy and quick implementation.

The REBA technique (Rapid Entire Body Assessment) is a postural analysis system sensitive to musculoskeletal risks in a variety of tasks which include the upper arms, lower arms, wrist, trunk, neck, and legs. It analyses the extent of external load/forces exerted, muscle activity caused by static, dynamic, rapidly changing or unstable postures, and coupling effects. In contrast, this method presents five action levels for evaluating the level of corrective urgency. (Kee and Karwowski, 2007)

After these considerations, it became apparent that it would be complicated to implement them. RULA, although very quick, only analysed individual activities and did not consider dynamic movements. The time it took to study using the other methods was not efficient due to process variations, box dimensions and weight not being constant across clients and having three operators with different physiological dimensions. Although not implementing these methods directly, they were considered and provided important information on what postures could represent a decrease in risk.

RULA form is presented in the Annex A. By analysing the steps needed to complete these forms, it is possible to understand that by reducing/removing individual or compound activities, without increasing the risk in the overall picture, improvements could be implemented that reduced the probability of contracting a MSD.

2.3 Time and Motion study

Time and motion study is a business efficiency technique used to improve and upgrade working systems, with applications ranging from all industries to service organisations, including banks, schools and hospitals.

This technique originated, in the image of *Ergonomics and Human Factors*, from the culmination of the theories established by Frederick Winslow Taylor (*Time Study*, from *scientific management*) and Frank and Lillian Gilbreth (*Workstudy*).

Frederick Taylor defended that the most significant inefficiency waste was not related to material waste but human resources (labour). Taylor introduced this method of dividing a task into several steps, measuring the time it takes to perform each step, and then determining the most efficient way of carrying it out.

Frank e Lilian Gilbreth were also dedicated to Workstudy but took a more motion-driven approach, trying to improve efficiency by reducing the number and length of certain movements. (Lopetegui et al., 2014). Kanawaty (1992) defines Workstudy as the systematisation of the task executing methods to use resources efficiently e establishing performance standards for each of the different processes.

Kanawaty (1992) describes the Workstudy as an essential tool for managing any production or operational unit, that:

- increases productivity by reorganising work and processes without investing large financial resources;
- is systematic, thus ensuring that none of the influencing factors will be neglected;
- may improve safety and working conditions by identifying possible dangerous activities.

Meyers and Stewart (2002) refer to the Time study as the most effective method of cutting production costs, and a simple process change could eliminate and automate several tasks. Although these authors mention that these types of studies can lead to dehumanisation by going to extremes, the method must be correctly applied, and the operators' well-being is preserved.

There are different methods of applying the Time study, as Meyers and Stewart (2002) defined: Timekeeping method, Pre-established times method, Work sample method, Standard times method and Time estimating. The first and the most used is measuring the time an operator takes to perform a specific task with a stopwatch. The pre-established times look at tabulated times and movements established beforehand to determine the total operational time. The Work sample method allows the measurement of operations that occur with irregularities or in different conditions. The use of Standard times provides a way of computing the time of a particular operation with the standard time of each element. At last, it is possible to use historical data or ask for opinions. This method, although being frequently used, is subjective and may not be representative of the actual situation.

As any method presented by any author, it follows a certain *path*, and as Kanawaty (1992) defined it, the timekeeping method is divided into eight steps:

1. Gather all the information and influencing factors of the process;
2. Create a detailed description of the process and break it down into elements;
3. Analyse the several elements to ensure that the methods and movements associated with each one are efficient and determine the sample size;
4. Measure the times for each element with a stopwatch and register the data
5. Check if the operator's working pace is considered normal (this step should be done simultaneously with the previous one);
6. Convert the measured times into basic times by multiplying it with a pre-established factor (only if the operators' pace is considered below normal);
7. Determine the allowed tolerances for considering a time above or below the basic times;
8. Determine the standard time for each element.

The first two steps are crucial to fully understand this process before starting the measurement phase. It is also essential that the operator clearly understands the study and why it is being done to encourage collaboration and avoid creating uncomfortable situations.

To determine the sample size, the minimum number of observations that ensures that the calculated average is close to the actual average needs to be determined, as it is going to be explained in the following subsection.

2.3.1 Time measurement

There are two methods to choose from for time measurement: continuous measurement and individual measurement. For the continuous method, a stopwatch starts at the beginning of the first element and is stopped at the end of the last, and at the end of each element, the time is registered. In the end of the analysis, these times are all subtracted to the previous element to determine how long each one took. The individual method only measures the individual elements, so the stopwatch starts and stops with that element.

As Meyers and Stewart (2002) stated, the continuous method is preferential because it represents reality better than analysing individual elements, making the study more reliable because it takes all into consideration, even *strange elements*. Meyers and Stewart (2002) defines these *strange elements* as all the elements that occur unexpectedly, that could happen or not in every cycle. These times could be considered productive (machine stops, equipment cleaning, among others) or not productive (talk with another operator, lace up the shoe, and others). The inclusion or not of these types of times should be analysed individually, which is why taking notes as the process flows is important.

The use of digital stopwatches allows these two methods to be applied simultaneously. The fact that these devices have internal memory allows for the registration of each time at the end of any element without stopping the total time.

2.3.2 Sample size

As seen before, the Time study accuracy depends on the number of observations made. Given the nature of the process, it is often impossible to register a large number of observations because it occurs at low frequency or is too expensive, for example. What is important, however, is to know the confidence and accuracy levels associated with each study because these factors guarantee that the calculated average is close to the real population average. (Cardoso, 1963)

According to Meyers and Stewart (2002), the accuracy used and accepted in these studies is 5%, with a confidence level of 95%, meaning that the average time has a 95% probability of being 5% above or bellow the population average.

In order to determine the minimum number of observations needed to achieve this confidence level, Cardoso (1963) proposes the Equation 2.1, that uses the sample average and standard deviation from an initial sample of 10 to 15 observations. If the number obtained by this equation is higher than the number of observations considered, new measurements must be taken until the result is lower than the considered sample size.

$$N_a = (40 \times \frac{\sigma_a}{\bar{X}_a})^2 \tag{2.1}$$

where: N_a =amount of observations
σ_a =sample standard deviation
$\bar{X}_a$ =sample average

These concepts were considered in this dissertation to measure potential improvements and compare AS IS and TO BE models clearly. With the measured times, it is also possible to identify potential wastes in each process.

2.4 Operations Research

Operations research is a discipline that deals with developing and applying advanced analytical methods to improve decision-making. It is applied to all sorts of industries, especially in logistics, to solve transportation and distribution problems.

2.4.1 Linear programming

Linear programming can be defined as the process of minimising a linear *objective function* while fulfilling a finite number of linear equality and inequality constraints. (Karloff, 2008).

Linear programming is a mathematical model for solving diverse and complex combinatorial problems, and came to change the approach and outcome of several real world problems to obtain, in theory, the scenario that best suits the objective, or as Dantzig (2002) described it, "Linear programming can be viewed as part of a great revolutionary development which has given mankind the ability to state general goals and to lay out a path of detailed decisions to take in order to *best* achieve its goals when faced with practical situations of great complexity". This model, allied with the techniques for solving the models (algorithms) and engines executing the steps of the algorithm (computers and software), can solve real complex problems.

The first mentions of this method began in 1947, after World War II, and the applications have been growing exponentially as humanity gets more computing power. Pre-1947, as Dantzig (2002) defines it, there were some mentions of the topic among programming-planing experts and scholars, but there was a lack of interest in trying to optimise, or in other words, none considered an objective function, so the purpose of these problems was to find a solution, not the best solution.

Dantzig invented the Simplex method that efficiently addressed most linear programming problems, but this time with an emphasis on finding the best solution to a particular problem. Linear programming was extensively used in the early formation of microelectronics, and it has been currently applied to company management, such as planning, production and transportation, since most companies want to maximise profits or minimise costs.

Standard form is the simplest way of delineating a linear programming problem, with three components:

- Objective function: this can be maximized or minimized, depending on the problem. c_1 and c_2 represent constants;

  e.g. $f(x_1, x_2) = c_1x_1 + c_2x_2$

- Decision variables: should be non-negative;

e.g. x_1, x_2

- Problem constraints: these inequalities define the values the decision variables may take.

$$\text{e.g.}\quad \begin{aligned} a_{11}x_1 + a_{12}x_2 &\leq b_1 \\ a_{21}x_1 + a_{22}x_2 &\leq b_2 \\ a_{31}x_1 + a_{32}x_2 &\leq b_3 \end{aligned}$$

As mentioned before, the Simplex algorithm made linear programming problems, modelled in the standard form, possible to be solved. This algorithm solves these problems by constructing a feasible solution at a vertex of a Polytope, with a series of linear constraints producing the geometric object that represents the feasible convex region of possible values for the decision variables.

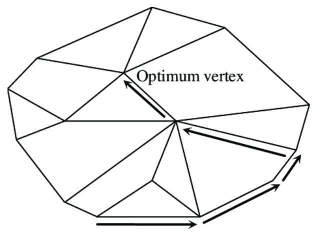

Figure 2.4: Simplex algorithm - a system of linear inequalities. (Safdarian et al., 2013)

After constructing the Polytope, the algorithm *walks* along a path through the edges of the feasible region to vertices that do not increase/decrease the objective function value until the optimum minimum/maximum is reached, in theory, every time, as can it be analyzed in Figure 2.4. In rare practical problems, regular versions of this algorithm may make it cycle, as Klee and Minty proved by constructing a family of problems that the Simplex could not find a solution in amount steps that grows exponentially with the problem size. For these types of problems, pivot rules were established by researchers.

2.4.2 Integer programming

Until this point, it was only taken into consideration two simple rules for this problem-solving model, that the variables should be non-negative and that the objective function and constraints should be linear. These considerations helped many mathematicians and operation researchers solve many problems. But what if it was added a new type of constraint? What if the problem required the variables to be integer or binary? In reality, many real-world problems fall in this category, and to solve them, other types of algorithms had to be created since the Simplex algorithm is no longer capable.

In theory, the simplest way of solving these types of problems is to remove the constraint that the variable x is an integer, solve the corresponding Linear Programming, and then round the entries of this solution to comply with the integer constraints. This method is known as *Linear programming relaxation of the Integer Linear programming*. Although being a straightforward approach, this method does not guarantee the optimization of the solution, nor that it is in the feasible zone, i.e., it may violate some constraints. Wolsey and Nemhauser (1999)

There are some exact algorithms like the cutting plane methods that can be used to solve integer linear programs exactly, like the *cutting plane* methods. These work by solving the LP relaxation and then adding linear contraints to drive the solution towards bring integer, without excluding any integer points.

Another class of exact algorithms are variants of the branch-and-bound method. This method, according to Lawler and Wood (1966), repeatedly partitions the space of all feasible solutions into smaller and smaller subsets, "and a lower bound (in the case of minimization) is calculated for the cost of the solutions within each subset". This continues until "a feasible solution is found such that its cost is no greater than the bound for any subset. A representation of this method is shown in Figure 2.5.

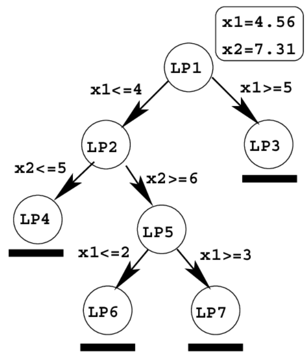

Figure 2.5: Tree representation example of the branch-and-bound method. (Deb and Pal, 2004)

There is also the Evolutionary algorithm that is based on the underlying idea that "given a population of individuals within some environment that has limited resources, competition for those resources causes natural selection (survival of the fittest)" (Eiben and Smith, 2015). Given an objective function to be maximized, the randomly created set of candidate solutions are elements of the function's domain. The fittest values are then mutated, creating another generation of candidate solutions. This process is iterated until a candidate with sufficient quality is found or a preset computational limit is reached.

2.5 Facilities Planning

This section contains the theory behind facilities planning, which served as the primary approach taken for the proposed alterations of the shipping layout.

2.5.1 Introduction and objective

Tompkins et al. (2010) defines Facilities Planning as the strategy organizations use to achieve supply chain excellence. As the author suggests, this approach has a broad range of applications, like a hospital, a production plant, a distribution centre, or any portion of these facilities.

To obtain this excellence, Tompkins et al. (2010) outlines six steps or levels, being business as usual, link excellence, visibility, collaboration, synthesis and velocity:

- *Business as usual*: a company should work hard to maximize individual functions of the supply chain, and individual departments must have the goal of being the best department in the company. Tompkins et al. (2010) considers that organizational effectiveness is not the emphasis;
- *Link excellence*: companies must become more homogeneous, eliminating any boundaries between departments and facilities, linking strategic and tactical initiatives at all levels;
- *Visibility*: providing the informational links so that everyone understands the ongoing status, minimizing supply chain surprises, requiring, this way, the share of information. This is considered the first real step towards supply chain excellence;
- *Collaboration*: this next step allows supply chains to determine how to best meet marketplace demands and works as a whole to maximize customer satisfaction while minimizing inventories;
- *Synthesis*: is a continuous improvement process that looks to unify all supply chain links to form a whole, creating a pipeline from the customer perspective.
- *Velocity*: is synthesis at the speed of light since nowadays, the internet created immediate orders and the customers expect them to be fulfilled.

Facilities are the critical components in the pursuit of supply chain excellence, so they must be planned in a way that the product will follow the supply chain series, with the ultimate customer satisfaction in mind. According to Tompkins et al. (2010), all facilities should have the following characteristics:

- Flexibility. Being able to handle most of the requirements without being adjusted;
- Modularity. Having systems that can cooperate efficiently over a range of different operating rates;
- Upgradability. Facilities that easily incorporate more advanced equipment and technologies;
- Adaptability. Being capable of supporting the changes that calendar, cycles and peals that may arise;
- Selective operability. This reflects the understanding of how a facility operates and allows contingency plans to be created;
- Environment and energy friendliness. The planning approach must consider recognizing and adopting a mindset of sustainability.

As mentioned before, facilities planning is the strategy companies use to obtain supply chain excellence to have a strategic competitive advantage. If *synthesis* is driven by customer satisfaction, so too should this be the primary objective for a facility planner. After considering customer satisfaction (that, through this study, will be parallel with fulfilling customer requirements), the planner can look to the enterprise requirements and vision, increase the Return on Assets (ROA), reduce costs, effectively utilize people, equipment and materials, maximizing Return on Investments (ROI) and assure sustainability and resilience. (Tompkins et al., 2010)

It is reasonable to assume that some of these objectives conflict. Therefore it is crucial to evaluate the performance of different solutions, making sure the best decision is made.

2.5.2 Facilities planning process

As one can imagine, a facility has a life cycle like most things in the real world. Although it is only planned once, it is frequently replanned to adjust it to the constantly changing objectives. The link between planning and replanning processes is the continuous improvement mindset.

In this regard, a facility planner must have the notion that continuous improvement is an integral element of the facilities planning cycle, as depicted in Figure 2.6. This process is not dependent on whether it is a new or existing facility to be planned, it is the same for either case. (Tompkins et al., 2010)

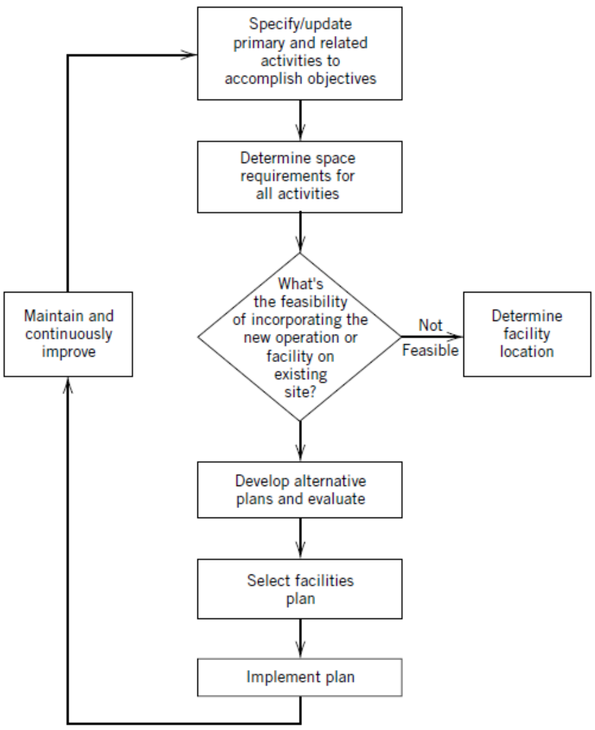

Figure 2.6: Continuous improvement facilities planning cycle. (Tompkins et al., 2010)

Although facilities planning is not an exact science, it can be organized by applying the traditional engineering design process. Tompkins et al. (2010) integrated the facilities planning process into the traditional engineering design process and then divided it into three phases (I, II and III). Tompkins et al. (2010) went a little further and also defined The winning facilities planning process: "in order for the facilities plan to be successful, a clearer understanding in needed of not only the vision but also the mission, the requirements of success, the guiding principles, and the evidence of success."

Phase I

Tompkins et al. (2010) defines this phase as the fundamental problem definition. First, it is essential to define (or redefine) the objective of the facility by specifying the products to be produced or services to be provided quantitatively.

Then, the primary and support activities to be performed in accomplishing the objective should be specified in terms of operations, equipment, personnel, and material flow involved.

To be a winning facility, according to Tompkins et al. (2010) is essential to understand in this phase the model of success, the internal and external issues, and establishing facilities planning criteria by obtaining organizational commitment.

Phase II

When the problem is defined, it is time to analyze it, generate alternatives, evaluate them, and select the best design. This is done by determining interrelationships and space requirements.

All equipment, material and personnel should be considered.

Phase III

The final phase is the implementation phase, where the plan is adopted, implemented and maintained.

This vital phase was considered because it is part of the process, but unfortunately was not part of this study because it did not coincide with ATEP timeline.

The topics addressed in this Chapter, served not only as a way to gather and analyse data, but also to shape the path of this study. Although being very different from each other, all serve a purpose in this improvement project.

Chapter 3

Current Situation and Major Inefficiencies

The following chapter composes an initial contextualisation of the products, clients and packaging processes, a problem presentation and the starting point for this project.

3.1 Process and Products contextualisation

The initial contextualisation considered in this section aims to give a clearer overview of all the packing procedures, product and material types, areas of interest and a brief description of each client's significant procedure variations. Only the information considered essential in understanding this shipping process will be given since all the sensitive information will be omitted, e.g. the client's and product type's real names.

3.1.1 Product characteristics

As mentioned briefly in Chapter 1, semiconductors are very delicate and fragile materials, so they must be handled and transported with extreme care. This product is very sensitive to particles and Electrostatic Discharges (ESD), so the production line must be located inside of a Clean Room.

A clean room is defined in the International Organizational for Standardization, standard 14644-1 as a: "room in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimise the introduction, generation, and retention of particles inside the room and in which other relevant parameters, e.g., temperature, humidity, and pressure, are controlled as necessary". (ISO, 1999)

The productive process begins with Silicon Wafers that arrive at ATEP from front-end factories with a specific number of Integrated Circuits (IC) or dies that through the production line are targeted by several operations, that in the end, result in ready-to-use chips, that can be installed in automobiles and cellphones, for example.

As already stated, Amkor follows a QualityFirst policy, or in other words, the company continually looks to produce components with zero defects, not only is it crucial to its clients but also because this helps to reduce costs, waste and other logistical problems. This is accomplished through the fulfilment of various specifications and regulations that protect the product and the operators involved in the production process. The product quality is inspected and verified through several checkpoints to ensure that the end product is in due compliance. This is especially important to the automotive industry since an error could result in a catastrophic event.

After all the production processes are done, the IC needs to be packed in a container capable of holding the material and keeping its integrity. ATEP's integrated circuits are shipped in four distinct supports, as one can see in Figure 3.1 and 3.2. The Figure 3.1.a) corresponds to an Horizontal Wafer Shipper (HWS) and 3.1.b) to a Front Opening Shipping Box (FOSB), carrying a certain number of wafers with 200 or 300 mm in diameter.

Figure 3.1: a) Horizontal Frame Shipper (left) and b) Front Opening Shipping Box (right) examples

In the Figure 3.2.a) and 3.2.b) can be seen an example of a Tape and Reel and Tray shippers, respectively, and in Figure 3.2.c) and 3.2.d) the cartoon boxes that hold these shippers.

Figure 3.2: a) Tape & Reel shipper (top left), b) Tray shipper (top right), c) Tape & Reel cartoon box (bottom left) and Tray box (bottom right) examples

These packages are then stored in different *Kardex* storage locations in the production line, that the shipping team has access to. After this stage, the responsible for the material handling is no longer the Production department, and the logistics team takes over.

The IC's and their packaging, i.e., the Horizontal Wafer Shipper, Front Opening Shipping Box, Tape & Reel, Tray Box, etc. coming from the production line, are defined as productive material throughout this dissertation.

All the material that does not come from the production line but it is necessary to complete the packing procedure is labelled as extra material. This material group comprises the cartoon outer and inner boxes, protective plastic, shipping labels, plastic tape, adhesive envelopes, crystal bags, clamps, air cushions, plastic film, plastic straps, protective foams, security stamps and empty boxes. Some types of products require specific types of extra material, but not every material defined as extra will be shipped with every type of product.

Aforementioned, these products are very sensitive to vibrations, humidity and ESD's, so in order to guarantee that these contaminations do not compromise the product, these shippers, without exception, are packed in some protection, for example, a Moisture Barrier Bag sealed in a vacuum. All of ATEP's production is Make to Order (MTO) because of all the different products and client requirements. These requirements will influence not only the production processes but also the packing and transport procedures. All of ATEP's clients will have different specific packing and procedure requirements, as will be detailed in the last part of this subsection.

3.1.2 Logistics Department

ATEP's logistics department is responsible for all the company's material movement and transactions, warehouse maintenance, and spare parts management. This department is responsible for the material transportation and storage, since its arrival at ATEP to its delivery to the production line, and after the material is cleared by production until it is collected by the courier company to be transported to its final destination. After being delivered to production and before being released, another department is responsible for the productive material handling.

The logistic execution at ATEP is subcontracted by one of the world leaders in the logistics services provision market, allocating full-time collaborators only to ATEP. These operators are responsible for the reception and dispatch of all the materials (productive, engineering and research materials), equipment and consumables that arrive at the factory and equipment movement through the production line.

This department is also responsible for the shipping area, the main focus of this dissertation, which will be described and defined in this chapter, and all different warehouses present at ATEP. The storage locations that will be considered in this study are the Incoming Warehouse, responsible for accepting incoming materials and equipment and storing the production line's more urgent needs, and the Central Warehouse, which holds most of the factory materials.

3.1.3 Packing, materials and clients

For this project, all of ATEP's major clients for productive material were considered since this study aims to improve the shipping area where they are packed and sent to their next destination.

ATEP has its own product cycle before turning into productive material. The first phase of this cycle begins with various samples sent to the client, which tests and decides which product type they intend to order. Following this decision, the second phase begins with the desired product type being shipped in batches to analyse if it is viable to the client and ATEP to have this business relation - during this phase, the type of material is categorised as Engineering material. The third and final phase begins after all the necessary changes have been made (this may be transport courier, packaging type or even on which days it is going to be shipped). Subsequently, the material switches to being defined as productive material. This is important to note since ATEP not only ships this type of material but many others that will not be included in this study since they do not represent the bulk of orders.

The shipping process has a standard packing procedure for all productive material for each of the different IC shippers that aims to make the packing process more homogeneous. With that, each client has a set of special requirements that applies to all or only a portion of its products that add variation to each procedure. The client is not the only process defining factor, the IC's carrier type and the product security level have influence too.

Throughout this dissertation, the clients will be mentioned as XFI, DNQ, VSN, LTI and HBR[1].

The product types and shippers by client are defined in the Table 3.1. The client XFI has products shipped in Tape & Reel with 13 inches, Multiframe Shippers and Horizontal Wafer Shipper, named throughout this study has TR, MFS and HWS product types, respectively. For the client DNQ only was considered the products shipped in Tape and Reel of 7 and 13 inches, designated by 2k7TR, 2k13TR and 4k13TR, and also HWS product types. The client VSN only has two types of products being studied, designated S and D, and both shipped in Tray Box. LTI product types that were considered in this project were TR, TB) and FOSB.

Table 3.1: List of productive material for each client

Client	Product Type	Shipper
XFI	TR	Tape & Reel
	MFS	Multiframe Shipper
	HWS	Horizontal Wafer Shipper
DNQ	2k7TR	Tape & Reel
	2k13TR	Tape & Reel
	4k13TR	Tape & Reel
	HWS	Horizontal Wafer Shipper
VSN	S	Tray Box
	D	Tray Box
LTI	TR	Tape & Reel
	TB	Tape & Reel
	FOSB	Front Opening Shipping Box
HBR	TB	Tray Box

[1] For confidentiality reasons, the client's real names and products will not be disclosed.

The last client that was considered was HBR, which at the time of this study was in the ramp-up phase, but was also considered since it will represent a bigger portion of the productive material production volume in the future. This client products types are shipped in Tray Boxes (TB).

All of these clients have very specific security requirements that need to be fulfilled due to security breaches that may cause irreparable damage to the company using them.

Each product may have one or more destinations to be shipped, which depends only on the product itself, and is defined by the customer.

3.1.4 Shipping area

As explained before, all the productive material shipped by ATEP is prepared in this area. This part of the factory comprises all the packing stations, material buffers, transport carts, packed material storage and all the equipment necessary for the packing procedure.

The objective of this area is to serve as the support for all ATEP's orders in the most efficient way possible while fulfilling all client requirements, with the limited space available, so the efficiency is not only measured in time and distance travelled by the operators, but also in correct space utilisation. All the products are picked by the transport courier here, so it also must store the packed material and have the right accesses.

This zone, as presented in Figure 3.3 has three different entry points: one that lets operators deliver the packed material and access the Central Warehouse, one to access the different *Kardex* locations, and last, a way into the Incoming Warehouse.

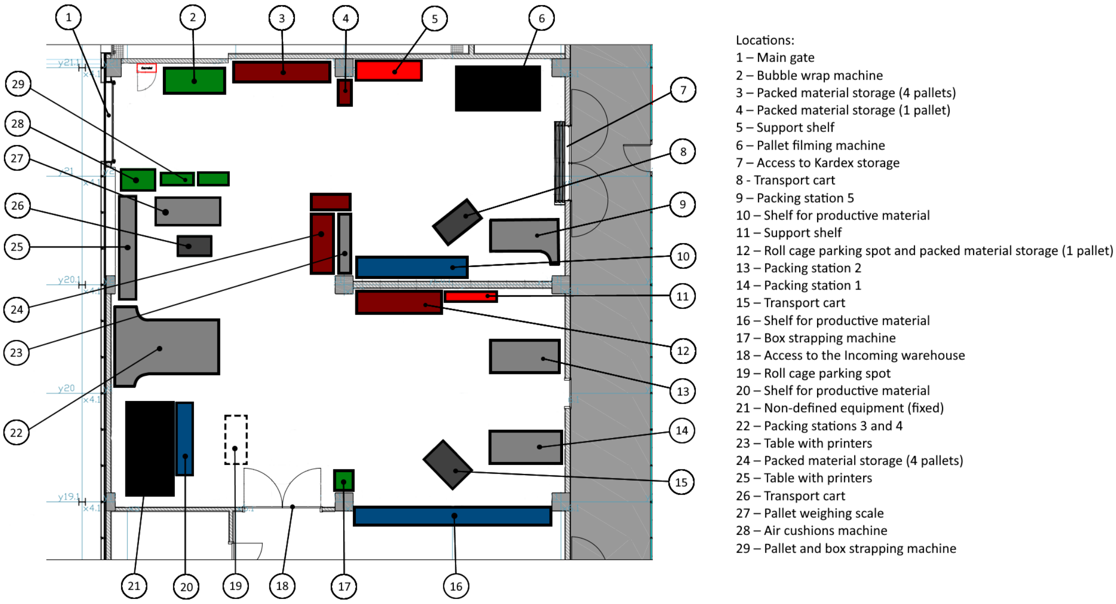

Figure 3.3: Current layout of the shipping area

The shipping team utilises some free space in the Incoming Warehouse to store the smaller extra material needed for the packing process, like the plastic tape, crystal bags, clamps, plastic films, and empty boxes. The protective foams and some inner and outer boxes are also stored in this area but as buffers.

The rest of the outer boxes and protective foams are stored in the Central Warehouse and are brought to the Incoming Warehouse according to demand. The larger outer boxes (P1, P2 and P3) and wood pallets are stored outside the Central Warehouse, protected from atmospheric conditions[2]. The *Kardex* locations are all in the same corridor, near the shipping area, and are defined as K1, K2 and K3, and store all the productive material.

This area, although not a storage facility, has to hold productive and extra material temporarily. The productive material that was cleared to be picked by the operator at the beginning of the procedure and that was not packed is stored on shelves to be shipped the next day, except for XFI's product types, which need to be stored back in a secure location. These shelves are painted gold in Figure 3.3. A portion of extra material is also held in this area as a buffer to lower the travel frequency between the shipping area and the assigned storage location.

The shipping area currently contemplates four packing stations that, as the name suggests, are where a large portion of the packing procedure occurs. There is also a smaller packing station that supports the other four stations and is used when the workload is higher than usual. Each packing station is assigned to one operator.

Four small transport carts do the material transportation (extra and productive), and each one is assigned to one operator, but, if necessary, one operator can use more than one. This depends on the volume to be shipped, and it is the operators' decision to lend the cart to others (three of these carts are painted green in the current layout, shown in Figure 3.3. The two Roll cages are used exclusively for productive material picking and temporary storage.

The dark red rectangles from Figure 3.4 represent the space available on the floor to store the packed material.

3.1.5 Shipping process overview

As mentioned before, this study will mostly pore over the shipping area at ATEP's. This area, known to house several inefficiencies capable of being eliminated, is where most of the shipping process happens and where most of the material and equipment needed are stored.

The basic packaging process begins with the daily plan of cleared productive material[3] being delivered to the operator by the client production planner. Each operator is assigned to one or two clients, and these are defined in Table 3.2, as well as the different destinations for each product type. The operator then sets out to the assigned Kardex storage for that specific client to pick the required lots of productive material.

These lots are then brought back to the shipping area and stay in a roll cage alongside other client products, separated, of course, by lots, product types, and clients. Using a roll cage as a mobile picking unit allows for a more dynamic picking process and more efficient utilisation of the limited space of the shipping area. This part of the process can be performed by any of the

[2] This location is defined as the canopy
[3] productive material must be cleared before being picked up

Table 3.2: Summary of the defined clients, product types, destination and operators.

Client	Product type	Destination	Operator
XFI	TR	XFI1	1
	MFS	XFI1	
		XFI2	
		XFI3	
		XFI4	
		XFI5	
	HWS	XFI1	
DNQ	2k7TR	DNQ1	3
		DNQ2	
	2k13TR	DNQ1	
		DNQ2	
	4k13TR	DNQ1	
		DNQ2	
	HWS	DNQ3	
VSN	S	VSN1	2
	D	VSN1	
LTI	TR	LTI1	2
	TB	LTI2	
		LTI3	
	FOSB	LTI2	
HBR	TB	HBR1	3

operators, not being assigned only to the operator that packs that specific client, reducing this way the frequency of travel needed to pick up all the productive material. The roll cage is then *parked* in an assigned parking spot, following the 5S implementation methodologies *Seiton*.

After this step, the operator brings a single (or multiple, depending on the productive material volume) transport cart to the roll cage to unload the required productive material that is going to be shipped. This intermediate transport car is used because the space the roll cage occupies may create congestion in this highly dynamic area, and its weight and steering will require more time to complete this task. The material is then transported to the packing station.

The operator then uses the computer to create the shipping documents, ask for the freight bill, and all the other *SAP* related activities. These activities were not analysed nor will be described in this document, as they were improved in a recent study. Some product types must be weighed before the document creation, so the operator must bring them to a weighing scale.

Creating these documents also gives the operator the quantities of extra material needed to be collected, so he must pass by all extra material locations scattered around the shipping area, the canopy, and the central and incoming warehouses. The operator only passes by the necessary locations, carrying a small pallet jack or a transport cart. After all the extra material is picked up, he comes back to the packing station and organises the material according to his preferences.

With all the material collected, the operator may now begin the physical packing procedure with the assembly of the cartoon inner[4] and outer boxes with plastic tape and then stick all the shipping labels (all product types have one or more shipping labels to be added). The cartoon boxes are half assembled by only closing one of the openings and then organised on the floor near the packing station in a certain way.

The packing control part of the process is done before putting the product inside the outer box to ensure that the specific material that is being packed goes with the right document inside the correct box. After this, it can be sealed with plastic tape and a security stamp and put again in the transport cart. When the cart reaches its total capacity, it is carried to a strapping machine to add extra protection to these boxes and ensure that it maintains its form during transportation. The strapping process is done in two different types of automatic machines, depending on the type and size of the outer box (if it is a small box or a pallet).

The last part of the physical packing process is applying plastic film to the strapped boxes, covering all the surface area. If the outer box is small, this process is carried out by hand in the packing station, using a plastic film roll, if the outer box is a pallet, the process is done in the automatic filming machine. This last part is only done in a limited number of products for a limited number of clients. The plastic films help the carton box maintain its form and give extra protection against dust and humidity. The packed material is then laid out in a transport cart or pallet, depending on how it will be shipped.

Finally, the operator must store the packed material in an assigned storage location in the shipping area (and this is done to clear space in the packing station, allowing the operator to continue his daily tasks). All the waste that results from this procedure is disposed in the assigned bins, and the operator uses the computer to perform the stock control, and sends all the documentation associated with the order to the client and transport courier. The shipping process is finished when the packed material is loaded in a van or truck to be sent to its final destination.

This is the standard packing procedure for productive material at ATEP. The specific procedure for each product type and client will have a slight variation, as it is described in the following subsections. Each client has a set of special requirements that applies to all or only a portion of its products that add variation to each procedure. The client is not the only process defining factor, the IC's carrier type and the product security level have influence too.

3.1.6 XFI Client

XFI's product types HWS and MFS are both considered secure products and have not only specific security demands but also particular storage and access requirements:

- these products are stored in a different location from other products;
- this location is only accessed by competent and security cleared personnel and are under constant surveillance;

[4] When needed

- the product may only leave this storage when is going to be dispatched, and should only be placed and handled in security cleared areas;

- the outer box that carries the productive material must be sealed with a security stamp.

The TR product type is not considered a secure product, so it has the basic security requirements. Next, it will be given a more in-depth characterisation of the shipping process for each XFI's product type.

HWS product type

After being collected, this product is packed inside the outer box involved in air cushions to assure the wafer integrity. One outer box has a capacity for one Horizontal Wafer Shipper. After being sealed with plastic tape and the security stamps, the material is then stashed in a transport cart, and when the cart is full or the amount to be shipped is reached, the operator drives the cart to a strapping station and the boxes are strapped one by one, and then taken back again to the packing station to be filmed by hand using a plastic film roll. The packed material is then transported to its assigned waiting spot.

The weight for this product is not constant since the number of wafers varies, but there is no need to weigh the material since a recent study defined the weight/wafer amount relationship.

MFS product type

At the time of this study, this product type had recently passed from engineering material to productive material.

One production lot of the product type corresponds to one Multiframe Shipper.

MFS is the only product that contemplates an inner cartoon box and two different security stamp types in its packing procedure, so after collecting all the material and assembling the inner and outer boxes, the operator loads the inner box with the productive material involved in a protective foam, which is then sealed with plastic tape and one of the security stamps.

This product can be shipped individually or in groups of four. The decision between these two options depended on the volume to be shipped to a single destination. The inner box is then packed inside the outer box, which is sealed with plastic tape and the other security stamp. If multiple lots are shipped, the four inner boxes are protected with air cushions inside a larger outer box before being sealed. Afterwards, the cartoon boxes are transported to a strapping machine to be strapped. The filming step is only done if the pallet box is used.

This product must be weighed before storing it in the assigned waiting spot, as there is no known relationship between the weight and the wafer amount.

TR product type

The TR product type for the XFI client is packed in groups of seven inside the outer box. The packing control occurs before sealing the outer box to ensure that no mistakes were made in document creation and that the suitable material goes with the right document.

The outer box is then sealed and transported to the strapping machine to be strapped. As the cartoon boxes used are not pallets, the filming process must be done by hand in the packing station, so the boxes have to return to this location to complete this step. After all the outer boxes are filmed, they are weighted and stored in the assigned waiting spot.

This material does not need any security stamps since it is not considered a secure product, as mentioned before.

3.1.7 DNQ Client

This client's product types do not need to be stored in a specific secure location, so all the productive material cleared until the operator's departure to pick this material is stored on an assigned shelf specific to this client.

Product types shipped in Tape & Reel

DNQ has three products types shipped in Tape & Reel, with 2k7TR having 7 inches in diameter and both 2k13TR and 4k13TR have 13 inches in diameter, so they need a larger cartoon box to house the productive material. These product types are explained in conjunction since their procedure variation is minimal.

A production lot for these products has a specific number of Tape & Reel boxes, and these values do not change for any product types. The outer boxes used for this client's packing procedure are specific to this client.

These product types do not need any extra protection, so after the outer boxes assembly, the operator puts the productive material inside the cartoon box, does the packing control procedure and seals the outer box. After this, each box is strapped and filmed. The packed material for these product types is organised on top of a wood pallet for organisational purposes but is shipped as individual volumes.

Product type shipped in Horizontal Wafer Shippers

HWS product type ships inside an outer box involved in a sheet of Air cushions, and the packing procedure for this product is very similar to the IFX's product type HWS, except for the security stamp that does not apply to this product, due to the DNQ security requirements.

For this client's product type, one production lot is equivalent to one Horizontal Wafer Shipper.

This product does not need to be weighted, so after the box has been sealed with plastic tape, the operator loads the transport cart with the cartoon boxes and takes it to a strapping machine to apply the plastic strap, and then comes back to the packing station to film the boxes by hand with the plastic film roll. The packed material is then organised in a pallet and stored in a waiting spot.

3.1.8 VSN Client

VSN has two product types, S and D, as stated before, and are shipped in TB. The two different product types shall not be packed inside the same outer box.

These products are separated in production batches, or lots, with a variable amount of units. These units are separated into trays and stored in a Tray Box, with a fixed quantity of units. As one could conclude, if the amount of chips is not the same in each lot, the amount of Tray Boxes is not going to be consistent either, and that is precisely the case. So, both of these products arrive at the shipping area in lots with 1 to 6 Tray Boxes, with most of the lots having 5 and 6 boxes. All these Tray Boxes are full except for the last one, which is often incomplete.

This client allows for different lots of the same product type to be shipped in the same outer box, but a lot must be packed in the same outer box, or in other words, a lot shall not be split. The number of Tray Box in every outer box must not exceed the outer box capacity.

This client packing procedure, which is the same for the two different products, considers three pallet outer boxes and three types of smaller outer boxes. The three pallet boxes are defined as P1, P2 and P3 and have a capacity of 16, 32 and 48 TB, respectively. The smaller boxes are labelled as C1 with a capacity for 2 TB, C2 with 4 and C3 with 6. The capacities for these boxes must be met, if the sum of the quantities of the combination of packed lots in an outer box does not reach the capacity for that box, an empty carton box must be added to ensure minimal movement of the Tray Box during transportation, e.g., if two lots with 6 Tray Box and a lot with 3 Tray Box are packed in a P1 outer box, the sum of boxes inside this outer box is equal to 15 in 16, and there is no other lot with 1 box available, an empty carton box must be added. These empty cartoon boxes are identical to the actual productive material but are, of course, empty.

The smaller outer boxes serve only as support for this client. Using P1, P2, and P3 boxes is preferable for logistics reasons. The distribution of the lots in the outer boxes is done by hand by the operator every day since the unit amount in the lots changes daily. This client's packing procedure aims to ship the minimum possible number of outer boxes, with the minimum number of empty boxes and the maximum number of lots.

The weight of the lot depends on the number of units and the product type. Currently, all lots are weighted by hand since the amount in the last tray box in a lot is not equal to its unit capacity.

This client also requires a security stamp to be added to the sealed outer box to ensure that the packaging has not been breached, leaving a mark when removed. Following this step, all outer boxes are strapped and then filmed, if it is a small box, the filming step is done by hand, if not is filmed in an automatic pallet filming machine.

3.1.9 LTI Client

As shown before, this client has three product types, TR, TB and FOSB, and will be divided into the next subsections to give a clearer view of the procedure variations for each type.

Products shipped in Tape & Reel

The TR product type is divided into production lots, and one lot corresponds to a Tape & Reel box. The collected productive material is wrapped in a bubble sheet and laid inside of the outer box, the packing control is done and then sealed. Next, the box is strapped and filmed, with all the shipping labels attached. The packed material is then stored in its waiting-to-be-shipped spot. The outer box for this client's product type is defined as I1, and has the capacity for ten Tape & Reel boxes. The rest of the packing procedure is the same as the XFI's TR product type.

The productive material is stored by lot in the assigned shelves, with the maximum number of cartoon boxes in height being 10.

Products shipped in Tray Boxes

The number of units in a production lot for this product type is constant, and one lot corresponds to one tray box. Depending on the number of lots to be shipped, the operator has to decide which outer box will be used. The outer boxes contemplated in this packing procedure are C1, C2 and C3 (having capacity for 2, 4 and 6 TB, respectively).

The productive material of this product type is stored in stacks of 3 boxes. The rest of the packing process is equivalent to the VSN client, except the use of security stamps.

Products shipped in Front Opening Shipping Boxes

This product type arrives at the shipping area in a FOSB carrying a specific number of wafers, and this value is constant.

To ensure wafer integrity, this material is packed inside I2 outer box with a pair of protective foams, and only one FOSB fit inside this outer box. This client does not require this boxes to be filmed, only strapped, so after sealing the outer boxes, they must be transported to the strapping machine and then weighted. The rest of this product packing procedure is standard.

3.1.10 HBR Client

Aforementioned, this client is in a ramp-up phase, so most of the parameters have not been defined yet, but will be very similar to the client's VSN, so the packing procedure variations for this client will be considered the same for VSN.

3.2 Problem description

As mentioned before, this project was proposed by ATEP to identify and propose improvements for its logistical processes, mainly in the shipping area, which is known to house several inefficiencies in some procedures because of the ever-changing market and client requirements.

This part of the factory represents, in some way, the visible outcome of the production line to its several clients, so ATEP puts much effort into doing things right. This means that this area has to be organised, and all the materials must be ready and accessible to use when needed, and the procedures are well defined and continuously improved to ensure that no time and motion is wasted, and making this area capable of fulfilling the export plan.

Even though ATEP strives to reach operational excellence and maximum efficiency, it also worries about the safety and well-being of its operators. This uneasiness reflects on guaranteeing that there are no production breaks, besides making the labour less fatiguing and intensive.

The achievement of these results is reflected by the three objectives established in this study, as they were defined in Chapter 1:

- Improvement of the shipping layout;
- Ergonomic and Human factors improvement of the several working stations;
- Packing process efficiency increase.

Although all these objectives are intrinsically connected, they were initially analysed separately. This was done to define a clearer view of what the study path may look like, and when the first ideas were formed and the current process defined, the methods of gathering and analysing data were selected, based on the literature review presented in Chapter 2. After establishing the main ideas, all these were tested iteratively to ensure no compatibility problems.

3.2.1 Shipping Layout

The improvement of the shipping layout was proposed by ATEP to prepare this packing zone for the arrival of a new customer (RBH) and new product (MFS), both with new procedures, cartoon boxes dimensions and product sizes, but also with attention to the current ones. There were several types of problems analysed in this study that were reflected in new and current products:

- Space occupied by the productive, extra and packed material that varies every day depending on the expedition plan;
- Space needed in the packing station and around it to perform the several operations, in the most efficient way possible;
- The operator movements are needed to perform several operations.

ATEP also wanted to analyse if it was viable to implement a system of storing the packed material that consisted in laying the different products separately, i.e., by product type, client and destination.

3.2.2 Working station ergonomics

As aforementioned, it is crucial for ATEP the health and well-being of its collaborators. The packing process is a very physically demanding job, with some load handling with high frequency. As described in Chapter 2, the risk of injury can be reduced by adjusting several risk factors without changing the clients' requirements.

In summary, overlooking this matter often creates situations where the probability of getting a MSD is increased, which most times results in a production loss. Besides not being efficient in operating this way, the company is responsible for putting practices in place to ensure the well-being and safety of its collaborators.

3.2.3 Packing process efficiency

As presented before, this company is placed in a very competitive and constantly changing industry, and this is reflected by the number of times that the requirements are changed by the clients. With these changes, many procedures are adjusted, creating sub-procedures that may represent non-value-added activities that could be improved.

To tackle this problem, a general definition of the procedures was done to understand the different variations that all the products and clients present to the overall packing procedure so they can be measured and potential improvements identified.

After this stage, a Time study was done (as defined in Chapter 2, Section 2.3) on all the different processes to identify potential bottlenecks or non-added-value activities that may be improved. Although the objective of this study was to identify possible improvements to be implemented, it also identified some inefficiencies related to everyday transactions and movements done by the operators that will not be mentioned since it was not the aim of this study. These were reported and handled by ATEP internally.

The improvements (proposed in the next chapter) were selected, created and implemented not only with a Lean thinking mindset to remove the already defined wastes but also by applying the PDCA cycle.

3.3 Initial Situation

All the activities in the shipping procedure were observed and analysed to identify which tasks had the most impact on daily operations in the shipping area and which could be improved in terms of efficiency and ergonomics. This process started

3.3.1 Shipping Layout

Understanding all the different procedures carried out in the shipping area was the first step to better comprehend the logistic process as a whole. The next logical step was to analyse how this physical space interacts with all of the processes, what the requirements needed for its operation and how the shipping area *behaves* and links with other departments.

As mentioned before, this area, besides being the space that houses most of the packing procedure, also has to be capable of storing material temporarily. With this, two approaches needed to be taken, one that analysed operators' movements and activities and another that studied the space requirements in terms of material storage and space of and around the packing station.

These two analyses will be detailed separately to better explain the methods and initial situations for both. Although explained separately, the results drawn for these two methods were iteratively created to ensure the best possible outcome.

Operators movements

To gather data for this analysis, a combination of Workstudy theory and Lean tools were applied to understand the current situation regarding operators' activities that require movement.

As mentioned in the previous subsection, these motions were necessary whenever the operator needed anything that was not at his disposal, that could be, for example, equipment or extra material.

This represented an opportunity for improvement by reducing the *muda* of **transporting** because of the poor layout configuration that might be causing an excess of movement. This could only be confirmed by gathering data for the Spaghetti diagrams and applying a motion study to understand if changing important locations is beneficial to each individual procedure that required these movements, but most importantly, if it is beneficial to the overall process.

As mentioned in Chapter 2, Tompkins et al. (2010) stated that, in order to obtain supply chain excellence, "companies must become more homogeneous, eliminating any boundaries between departments and facilities. To contribute to this step, a meeting was arranged with the Industrial Engineering (IE) department, responsible for most of the improvement projects done in the production line, to understand how the factory does these studies.

The IE department provided an internal tool that gathers data for creating the Spaghetti diagrams. This *MS Excel* application was capable of dividing the overall task into individual activities and registering all the locations that the operator could go to. This tool is the intellectual property of ATEP, so no images describing its functions will be shown.

The gathered data allowed for a better understanding of the overall movements each operator performed for his assigned client, by measuring the number of movements and then computing a distance matrix for all the locations, it was possible to know the travelled distance for both individual activities and the overall procedure. An example of one the distance matrices used is presented in Figure 3.4, where all locations are numbered from 1 to 28.

By collecting this data, it ended Step 3 of Creating Spaghetti diagrams, according to Daneshjo et al. (2021). To ensure that this study was representative of the actual situation, the operators were correctly informed and asked to behave like they would every day.

The data was, as said before, given in two forms: a Spaghetti diagram and values for overall movements for each operator. All spaghetti diagrams are present in Annex B to present a clearer image, and should accompany this analysis.

From / To	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1		8	16	16	14	9	14	18	24	33	31	25	22	23	27	34	12	16	10	9	12	61	123	157	101	269	41	45
2	8		7	14	12	15	24	27	30	37	36	29	30	31	30	37	21	24	18	17	19	58	120	154	109	277	49	53
3	16	7		9	11	16	25	28	31	40	42	35	38	39	32	39	22	24	19	18	21	53	115	149	110	278	50	54
4	16	14	9		11	15	24	27	30	38	35	29	32	33	30	37	22	24	18	21	24	47	109	143	117	285	50	54
5	14	12	11	11		11	20	23	26	44	41	35	27	28	27	34	19	21	14	17	20	56	118	152	114	282	44	48
6	9	15	16	15	11		8	11	14	22	19	13	16	17	17	24	8	10	8	12	15	61	123	157	109	277	35	39
7	14	24	25	24	20	8		3	6	14	11	11	16	17	9	16	15	17	16	21	24	70	132	166	117	285	35	39
8	18	27	28	27	23	11	3		3	13	10	13	18	19	7	14	18	20	17	22	25	72	134	168	119	287	37	41
9	24	30	31	30	26	14	6	3		14	12	16	21	22	8	15	20	22	19	24	27	74	136	170	122	290	40	44
10	33	37	40	38	44	22	14	13	14		2	8	18	19	5	12	29	31	29	34	37	84	146	180	133	301	36	40
11	31	36	42	35	41	19	11	10	12	2		6	16	17	23	25	27	29	27	32	35	82	144	178	130	298	31	35
12	25	29	35	29	35	13	11	13	16	8	6		10	11	8	15	21	23	23	28	31	75	137	171	123	291	25	29
13	22	30	38	32	27	16	16	18	21	18	16	10		2	13	20	17	19	17	22	25	77	139	173	117	285	26	30
14	23	31	39	33	28	17	17	19	22	19	17	11	2		14	21	18	20	18	23	26	78	140	174	118	286	27	31
15	27	30	32	30	27	17	9	7	8	5	23	8	13	14		7	24	26	24	30	33	77	139	173	127	295	32	36
16	34	37	39	37	34	24	16	14	15	12	25	15	20	21	7		31	33	31	37	40	84	146	180	133	301	36	40
17	12	21	22	22	19	8	15	18	20	29	27	21	17	18	24	31		2	4	9	12	68	130	134	106	274	38	42
18	16	24	24	24	21	10	17	20	22	31	29	23	19	20	26	33	2		6	11	14	70	132	164	108	276	40	44
19	10	18	19	18	14	8	16	17	19	29	27	23	17	18	24	31	4	6		5	8	64	126	160	102	270	38	42
20	9	17	18	21	17	12	21	22	24	34	32	28	22	23	30	37	9	11	5		3	63	125	159	97	265	43	47
21	12	19	21	24	20	15	24	25	27	37	35	31	25	26	33	40	12	14	8	3		66	128	162	94	262	46	50
22	61	58	53	47	56	61	70	72	74	84	82	75	77	78	77	84	68	70	64	63	66		62	96	160	328	96	100
23	123	120	115	109	118	123	132	134	136	146	144	137	139	140	139	146	130	132	126	125	128	62		34	222	390	158	162
24	157	154	149	143	152	157	166	168	170	180	178	171	173	174	173	180	134	164	160	159	162	96	34		256	424	192	196
25	101	109	110	117	114	109	117	119	122	133	130	123	117	118	127	133	106	108	102	97	94	160	222	256		80	140	144
26	269	277	278	285	282	277	285	287	290	301	298	291	285	286	295	301	274	276	270	265	262	328	390	424	80		466	470
27	41	49	50	50	44	35	35	37	40	36	31	25	26	27	32	36	38	40	38	43	46	96	158	192	140	466		4
28	45	53	54	54	48	39	39	41	44	40	35	29	30	31	36	40	42	44	42	47	50	100	162	196	144	470	4	

Figure 3.4: Distance matrix for Operator 1

In the Spaghetti diagram is represented every movement performed from one location to another, the thicker the line, the higher the frequency of movement. A colour code for the line also differentiates what stage of the packing procedure that movement belonged to. The blue lines correspond to the picking productive material activity, the dark grey ones are the picking of packed material to be delivered to the transport courier, and the orange lines are all the steps in between. The main reason for this is, that although the distances for these movements could be reduced, these are non-optional movements, as the operator will always have to deliver the packed material and pick productive material to and from, respectively, the same locations. As such, this could not be changed, so it allowed for a better realisation of where there could potential movement wastes, related or not, to the process.

Only the overall travelled distance will be presented, as the idea for the change is to make the area capable of every process, not individual activities. The bigger picture given by these values makes it easier to ensure that all the changes made a global improvement, and not only for that specific activity.

The diagram presented in Figure B.1 shows a lot of movement to/from the packing station from/to distant locations. Some improvement could be implemented by understanding the reasons behind these excessive movements. After analysing the data, it became clear that this operator needed more space around its packing station to store extra material. Some problems with the weighing process of a specific product type, and the opportunity to reduce the distance to a particular type of equipment, were also identified.

This operator's overall travelled distance per week is presented in Table 3.3, resulting in 11907 m.

Table 3.3: Travelled distance per week by Operator 1 (AS IS)

Client	Travelled distance AS IS
XFI	11907 m

As shown in Figure B.2, the problem was similar to the last but slightly more extreme. Besides needing more space on the packing station, it is also needed around it. It became clear that extra material needed to perform this client's procedure should be stored in the packing station because of the small dimensions and overall consumption.

As explained in the previous chapter, VSN utilizes P1, P2 and P3 outers that are stored in the canopy, and this distance showed potential to be decreased. The distance travelled by this operator in a week is 10818 m, as shown in Table 3.4.

Table 3.4: Travelled distance per week by Operator 2 (AS IS)

Client	Travelled distance
NSV and LTI	10818 m

The spaghetti diagram illustrated in Figure B.3 presented the least potential for improvement since it had enough support for its operations, but placing equipment near it could decrease the overall travelled distance travelled. As done before, the result of the motion study is displayed in Table 3.5, that amounted to 6807 m travelled by operator 3 in a week.

Table 3.5: Travelled distance per week by Operator 3 (AS IS)

Client	Travelled distance
DNQ	6807 m

Space requirements

In order to study the space requirements, the definition of space is needed before proceeding. In this case, it represents the available area an operator has around and on the packing station to perform the main operations[5], and the space required to store productive and packed material.

Before this study, this topic was only addressed when the need came, i.e., when there was a need for space, quick arrangements were made to correct it. The idea of how much space an operator needed depending on the production volume was not addressed, and this by itself already represented an opportunity for improvement.

The packed material was stored on the ground, in defined areas (only being separated by client) by the operator in the closest spot available. The productive material was laid on any of the available shelves, and the space around the packing station was not defined by any production volume, and sometimes became too over-crowed for certain operators.

Although the packed material did not have any specific rules, only that it should remain inside this area, the same cannot be said for the productive material and the outer boxes for two reasons. Firstly, since it is a very delicate unit, clients require a particular form of organising their products when stored outside of the *kardex*. Then, ATEP required its operators to place the open carton boxes in a manner that conserved both the safety of its operators and the box conditions.

[5]These are the operations that take the most space due to their expedition volume and outer boxes dimensions

The existing space in the current layout was measured, for these three activities, to have a starting point for the study and to compare them to the final results. The initial situation for the available area in the packing station can be seen in Table 3.6.

Table 3.6: Area available in the current packing stations.

Packing station	Area AS IS (m^2)
1	4.390
2	4.390
3	3.728
4	3.728
5	11.22

The measurements of the available area for productive material storage were, are presented in Table 3.7.

Table 3.7: Available area for productive material storage.

Client	Area AS IS
DNQ	6.372 m^2
Rest	20.963 m^2

Defining the space needed for each product type, client and destination represented the second step in the continuous improvement facilities planning cycle, proposed by Tompkins et al. (2010).

3.3.2 Working station Ergonomics

To understand the initial situation for this problem, all processes were analysed to identify which activities represented the most significant risk factors. Interviews were also conducted with the operators to have their input and recognise which actions resulted in the most discomfort. Due to the various requirements imposed by clients, the scope of the problem is restricted to activities that do not involve these requirements. This represented the first step in this intervention process.

After the initial analysis, it became clear that there were two activities that all operators complained about: **load/unload of the transport carts** and the **application of plastic film**. This was later confirmed by observing the packing process.

The load/unloading of the cartoon boxes also had awkward postures needed to fill the transport cart and required the most force in this process since loading and unloading were made two or more boxes at a time.

As seen in Figure 3.5, the lower platform of the transport cart is too close to the ground, so the operator needs to squat or bend his back to fill it with material.

Wrapping the cartoon boxes with the plastic film was repetitive motion, where a considerable amount of force was applied (due to the awkward movement needed to use the roll to wrap a big weighted box) for long periods. The posture was also not ideal since the dimensions of the boxes

Figure 3.5: Transport cart used by the shipping team.

vary considerably in a static packing station. The operator had to bend his back to reach the bottom of the box due to the workbench height being too low.

3.3.3 Packing procedure efficiency

Although the primary study done to find activities with potential for improvement was the Time study, the Motion study done with the help of Spaghetti diagrams also yielded some interesting results that inspired one of the solutions, as will be presented in this subsection.

VSN client

After closely analysing the data gathered for this client, it became clear that there was one activity performed by the operator in this client's procedure that could be automated.

The production lots distribution by the several outer box options, detailed in the previous section, was done by the operator by hand, responsible for creating the best possible scenario. The complexity of this problem depends on the number of different lots needed to be shipped, so the time to complete this task will increase with the increase in complexity.

The amount of hours needed to perform this activity can be seen in Table 3.8. The time needed to complete this task is the average of all the measured times, and this average is representative of the actual situation since the number of the taken measurements were higher than the number given by the Time and Motion study method (Equation 2.1). This time was then multiplied by the existing and expected number of documents for 2021 and 2022.

Table 3.8: Amount of hours needed to perform the lot distribution activity.

Client	Product type	2021	2022
VSN	S and D	75.68 h	71.45 h

It is estimated that almost 76 hours were spent executing this action in 2021, and that more 71.45 h will be consumed in 2022.

MFS product type

When gathering data for this product Spaghetti diagrams, it was noted that there were an excessive number of necessary travels done by the operator to the weight scale, later confirmed by the Spaghetti diagram itself. A detailed representation of this diagram is shown in Figure 3.6.

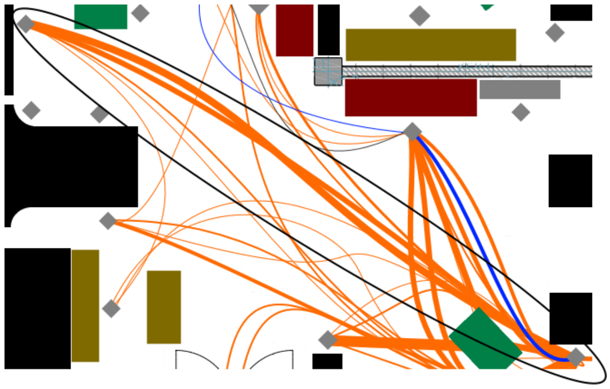

Figure 3.6: Spaghetti diagram portion for Operator 1 showing the movement excess.

As mentioned in this product description, this product must be weighed before being stored. Although it is a new product, this action is standard and done with other products, which should not represent the amount of travel registered. After close inspection, the reason for this motion waste was the fact that the dimensions of the outer box limited the number of lots that could be transported in the transport cart at once.

The measurements taken in the motion study are presented in Table 3.9. According to production forecasts, the travelled distance by the operator performing this activity is predicted to be 9895.2 m in 2022.

Table 3.9: Travelled distance in the weighing activity in 2022.

Client	Product type	2022
XFI	MWS	9895.2 m

The time spent carrying out this activity in 2022, according to the same forecasts, is expected to be around 25 hours of annual labour, as shown in Table 3.10.

Table 3.10: Amount of hours needed to perform the weighing activity.

Client	Product type	2022
XFI	MWS	25.76 h

This chapter presented the initial contextualisation, the problem description and, in the end, the starting point for this project was given. In following Chapter, each one of these topics will be addressed when proposing improvements, in order to conclude each objective.

Chapter 4

Results

The proposed and implemented improvements in this study will presented in this Chapter, that resulted from the inefficiencies and problems identified. These improvements will be accompanied by a benefits and cost analysis.

4.1 Proposed solutions

4.1.1 Shipping layout improvement

The Facilities planning approach defined in Chapter 2 was taken to propose an effective solution. After defining the objective and specifying the products and clients, the primary and support activities were specified. Although the focus of this study was to prepare this area for the productive material expedition (primary activity), attention to support activities was also given since this area is also responsible for performing them. These secondary operations will not be defined in this dissertation as they were not considered essential by ATEP.

After this stage, all the space requirements needed to be defined for activities and material storage. Besides the model created to predict these requirements (detailed in the following subsection), Spaghetti diagrams were created to ensure that it was a capable and efficient facility.

To design the solution to this problem, all characteristics proposed by Tompkins et al. (2010) were considered, as well as attention to the steps needed to obtain supply chain excellence by constantly communicating and interacting with the decision-making responsible and operators, ensuring that not only it complies with the company's vision, but also it functions with other parts of the factory.

Operators movements

As seen in Chapter 3, the operator's movements could not be considered efficient because of the excess number of movements, travelled distance, and disorganised movements. This was identified because of the way this area was designed, with small *sub-zones* that aggregated the same type of equipment or the same type of storage. Although this area was organised and functioned correctly, it was not efficient. A different approach and new mindset were needed.

This significant change was treating this area as a production line: the *raw* material that entered this area as productive material, and the product left at the end as packed material. In between, several processes were applied to the product, categorised as the activities done by the operators, like laying the productive material inside the outer boxes or applying the film.

With all the processes defined, it was possible to analyse which procedures needed specific equipment and certain types of extra material. The basic idea applied to reduce the *muda* of **transporting** was to centralise equipment that was needed by all procedures and individualise equipment only required by one procedure by placing it near the specific packing station. Besides equipment rearrangement, there was also intended to give operators a way of picking and temporarily storing extra material near the packing station when needed.

This approach was adopted to try to create a *leaner* procedure by reducing the amount of travel required. These considerations were half of the problem. To propose a well-reasoned improvement, the space requirements needed to be addressed.

Space requirements

As presented in the initial situation description, the idea of how much area was needed for a particular procedure was not analysed, and it represented a problem for ATEP since the arrival of new products with larger dimensions, and by maintaining current ones, could result in an overcrowed space, thus reducing the process efficiency as a whole. A model was created to predict the area required in this area, based on the factory's production plan. This plan consisted of the weekly predicted to be shipped amount of units for all product types every week until mid-2023.

By defining all the clients, products, materials, destinations and procedures, and by inputting material dimensions, a model could be created that could predict the space needed to store productive material temporarily and packed material but also predict the area required to perform the packing procedure, both on and around the packing station. To achieve this, only the way these individual components (products, clients, different types of materials) interacted with each other needed to be defined.

This model was implemented through a *Microsoft Excel* tool, producing three types of results:

- The area occupied by productive material, after being picked from the *Kardex* locations and before being packed;
- The area needed in the packing station to house all of the half-assembled outer boxes before being used in the packing procedure;
- The space needed to store the packed material before being picked up by the transport courier.

The interaction between its components must be defined to reach these results. The model used to calculate these requirements is presented and defined in Annex C, where these interactions are explained. Although not presenting the used values, it showed how the calculations were done for a specific client as an example.

The final results used to define the space requirements are presented next, compared with the measurements specified in the initial situation.

- **Productive material storage:**

The final results given by the prediction model are presented as the area needed for DNQ separated from the rest of the clients since DNQ was the only client with a specific storage location for productive material, as shown in Table 4.1.

Table 4.1: Comparison between the available and needed area for productive material storage.

Client	Available area	Area needed
DNQ	6.372 m^2	8.756 m^2
Rest	20.963 m^2	25.635 m^2

The required area is higher than what is available for both cases, and this should be addressed by increasing the available area on the workbench surface.

- **Packing area**

The values presented in table 4.2 correspond to the final results given by this study and represent the area needed around each packing station.

Table 4.2: Area needed around the packing station during the packing procedure.

Packing station	Area AS IS	Area needed
1	7.5 m^2	13.68 m^2
2	3.75 m^2	2 m^2
3	2 m^2	N/D
4	6 m^2	6.34 m^2
5	4 m^2	N/D

Considering the time range of this analysis, it became clear that two packing stations (1 and 4) needed to be adjusted. The first needed an expansion of at least 6.18 m^2 to reach the 13.68 m^2 minimum, and the second only required a minor adjustment of 0.34 m^2.

It was impossible to determine these values for packing stations 3 and 5 since they were not considered in the standard packing procedure.

- **Packed material**

Most of the outer boxes are designed to fit in a wood pallet without wasting any space, so the most efficient way of organising these products was already known for these cases. Since ATEP asked products to be separated by destination, and these product types were already in a situation of optimal placement in a pallet, the notion of a slot was created.

As shown in Figure C.11 from Annex C, these slots have the exact dimensions for almost all of the products, apart from DNQ's product types having a slightly higher height. This notion was created for logistic purposes and to maintain process consistency since the products were already placed in a wood pallet. The final number of slots needed is presented in Table 4.3. This value resulted of the final step in the prediction model presented in Annex C.

Table 4.3: Comparison between existing and required number of slots.

Number of slots AS IS	Required slots
10	28

After analysing all this data, it became clear that all this areas must be expanded to keep with this increase in demand. The productive material storage should be increase, as well as the space around specific packing stations, and major improvement to the packed material slots.

Proposed layout and benefits

The new layout for the shipping area at ATEP was not only the result of the two studies presented before, following the steps presented by Tompkins et al. (2010) in the *Facilities planning* book, but also the culmination of several mindsets presented in Chapter 2. The proposed layout is presented in Figure 4.1.

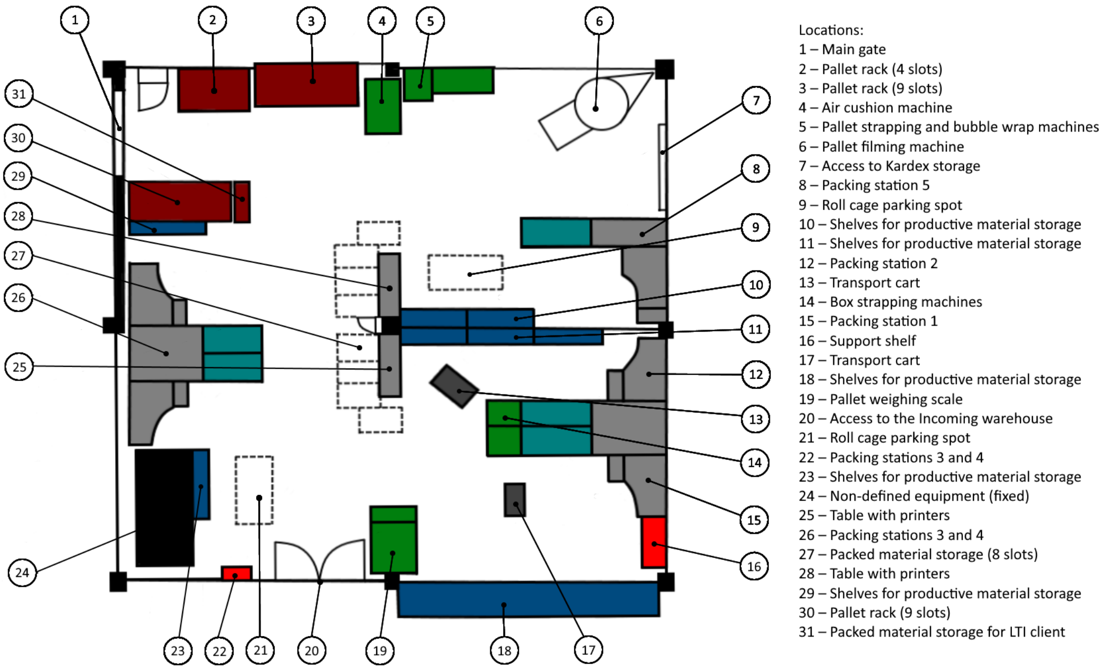

Figure 4.1: Proposed layout alterations.

After defining all requirements, the most significant warning was the number of slots that needed to be created. As shown in Chapter 3, the current layout only had 11 slots, which must be addressed before considering the rest of the components. The area around the main entrance (where the transport courier picks up the product) was filled with three racks, with a capacity for 22 slots. A small shelf (capable of holding the weekly demand for LTI's products) was added near the third rack to create more efficient storage.

The considered packing stations were designed to contemplate a smooth flow of product movement. All packing stations now contemplate a shelf near it, where the operator can store the productive material and even extra material if needed. This overall capacity for productive material storage expansion, as four new shelves were added and current ones maintained, resulted in a 50% increase for DNQ products and around 64% for the other products, as shown in Table 4.4. The DNQ client was separated since it was the only client with a specific location to stock its products.

Table 4.4: Productive material available area improvements.

Client	Area AS IS	Required area	Area TO BE	Var
DNQ	6.372 m^2	8.756 m^2	9.558 m^2	50 %
Rest	20.963 m^2	25.635 m^2	34.427 m^2	64.23 %

The workbench now has more space where required, as seen in Table 4.5. The packing stations suffered a slight increase in available area (1 and 2 from 4.39 to 6.033 m^2, and 3 and 4 from 3.728 to 5.268 m^2) to support the demand increase. The fifth station had its area decrease since it only serves as support to this area. The rehabilitation of one of the packing stations into a fully efficient one was asked by ATEP.

Table 4.5: Packing station available area (desk surface) comparison.

Packing station	Area AS IS	Area TO BE	Var
1	4.390 m^2	6.033 m^2	37.43 %
2	4.390 m^2	6.033 m^2	37.43 %
3	3.728 m^2	5.268 m^2	41.31 %
4	3.728 m^2	5.268 m^2	41.31 %
5	11.220 m^2	4.520 m^2	-59.72 %

The space around the packing station also must be adjusted as seen in the previous subsection. The changes to this area are shown in Table 4.6.

Table 4.6: Area available around the packing station adjustments.

Packing station	Area AS IS	Area needed	Area TO BE	Var
1	7.50 m^2	13.68 m^2	15 m^2	100%
2	3.75 m^2	2 m^2	5 m^2	33.3%
3	2 m^2	N/D	5.25 m^2	162.5%
4	6 m^2	6.34 m^2	8 m^2	33.3%
5	4 m^2	N/D	9 m^2	125%

Bringing the strapping machines to the end of the packing stations that needed them removes the necessity of transporting all the material to be strapped, further contributing to reducing the amount of travel done by the operator.

To reach the 28 needed, 8 slots were considered in the centre of the shipping area, on the floor, and are represented by the interrupted line squares in the middle of Figure 4.1. There are now 30 slots present in the shipping layout to store the packed material, surpassing once again the required number of 28, as shown in Table 4.7.

Table 4.7: Comparison between existing and required number of slots.

Number of slots AS IS	Required slots	Number of slots TO BE	Var
10	28	30	300%

The rest of the equipment and components of this area were maintained, but some changed to different locations. Some extra material buffer locations were also changed, bringing them closer to the operator. Besides being capable of meeting space requirements, this proposal also improves the packing procedure as a whole by reducing the total distance travelled by each operator, as presented in table 4.8.

Table 4.8: Comparison between the travelled distances in the AS IS and TO BE models.

Client	Travelled distance AS IS	Travelled distance TO BE	Var
XFI	11907 *m*	10938 *m*	8.14%
NSV and LTI	10818 *m*	7776 *m*	28.12%
DNQ	6807 *m*	6012 *m*	11.68%

This resulted in a slight decrease in weekly distance travelled of about 8% for Operator 1, 28.12% for Operator 2 and 11.68%, that summed up results in a total reduction of 4856 *m* for the shipping team. The Spaghetti diagrams that resulted from these changes are presented in Figures B.4, B.5 and B.6 from Annex B.

Costs

The proposed layout alterations require the acquisition of three sets of racks. ATEP has already started conversations with its internal supplier, but, unfortunately, no value was defined at the time of this study. After market research, it was concluded that the considered stacks cost around 2100€.

The rest of the added shelves came from another area of the factory, where they were obsolete, so it did not represent a cost to the organisation.

4.1.2 Workstation ergonomics

The two activities that represented the more considerable risk of contracting MSD's were analysed separately and solutions were drawn to reduce this risk.

Film application solution and benefits

When the film application process was analysed, one of the questions made to the process responsible was the reason why these boxes could not be placed in a wooden pallet and automatically filmed in the machine present in this area, as many logistics companies do. The answer was that is not possible since most clients demanded that the products be sent individually.

However, maybe, the wrong question was being asked. The real question was why this was part of the current procedure when any client did not require it. Removing this activity for the overall packing procedure eliminates the need to perform this physically demanding task. Unfortunately, any change to the standard packing process needs to be agreed upon with the client since it may alter the quality and integrity of the box when it arrives at the client.

Besides proposing the removal of this activity from the packing procedure, it is also proposed the acquisition of several height adjustable tables that can quickly change their height to adapt to the various product types considered in this study. By changing this height to pre-defined values, the operator ensures that his back is not bent and the arms do not exceed the 45º angle it makes with the spine. This solution should be applied if the clients reject the first option.

These pre-defined values depend on the physiological dimensions of the operators. They ensure that he stays standing erect and that the arms do not surpass the 45º mark. An example of these tables can be seen in Figure 4.2.

Figure 4.2: Height adjustable table example.

Load/unload the transport cart solution and benefits

A new type of transport cart was considered to ensure that no operator awkwardly positions his body to perform the loading and unloading activities. This type of transport cart allows this activity to be continuously performed at the same height by using a spring to elevate the transport platform. By placing boxes on top of this platform, the weight of the boxes forces the spring to find a new equilibrium, adjusting the height of the top box to be the same as the platform had before, meaning that the operator always loads and unloads boxes at the same height. An example of this type of solution is presented in Figure 4.3.

Figure 4.3: Ergonomic transport cart example.

This removed the operator's need to get down and place cartoon boxes on top of the lower platform, correcting the posture needed to perform this activity and making it more ergonomic by reducing the risk factor. As the transport cart had the same capacity as before, the other risk factors remained unaltered and guaranteed that this improvement did not increase the amount of transporting movements.

Costs

The acquisition of this equipment is the only cost associated with this ergonomic study. The two types of height adjustable tables considered in this study are shown in Figure 4.4. The main difference between the two is that the table on the right can lift and descend more oversized loads. There are two options for the table on the left: manual or automatic. The manual version costs 190€/unit, and the automatic 680€/unit, both being available in the national market. The option on the right has to be imported from China and costs around 1200€/unit.

Figure 4.4: Different types of adjustable height tables.

The ergonomic transport mentioned previously also needs to be imported since the specific dimensions required for this solution were not available in the national market. The price for this equipment was around 450€, plus transportation costs.

4.2 Implemented Solutions

Aforementioned, two activities identified in the packing procedure of two clients could be automated. Both of these improvements were implemented during this study.

4.2.1 VSN client

Removing the need to rely on the operator to reach the best possible scenario was, without a doubt, not efficient enough. Besides having the possibility for human error, it was a repetitive task that could be automated.

After understanding the problem, two options were considered to reach a solution. The first was to create a computer program that would solve the problem using the operator ratiocination, and the second was to compute the Linear programming model. The first option was quickly abandoned because it increased process efficiency but did not ensure the best possible solution or close to it, which was what the second option offered. The definition of the implemented model is explained in detail in Annex D.

Costs

The only cost associated with this implementation was the time spent developing this solution, so it did not represent any relevant costs to the organisation.

Benefits

By removing the responsibility of being the operator to perform this activity and placing it on an automatic computer tool, it was possible to remove two wastes, defined in Chapter 2 as *muda* and *muri*. The first, by removing non-value-added steps in a process considered susceptible to human error and non-efficient, and the second, by removing the overburden deposited on the operator of having to distribute the lots, when the task could be automated, the process was improved.

A Time study measured these improvements for a better understanding of their impact. These study results are presented in Table 4.9.

Table 4.9: Amount of hours needed to perform the lot distribution activity before and after improvements.

Client	Product type	2021	2022	2021 Improved	2022 Improved	Var
VSN	S and D	75.68 h	71.45 h	10.06 h	9.50 h	86.70%

Besides removing defined wastes, this tool's implementation allowed for a reduction of a total of 65.62 hours in 2021, and 61.95 hours in 2022, representing a variation of over 86%.

4.2.2 MFS product type

An *MS Excel* tool was created to reduce the number of travels done by the operator in this product packing procedure, which could store and calculate the packed material's overall weights. This information must be congruent with the information present in shipping documents.

The problem was simple, if the wafer amount to weight ratio was known, calculating the overall weights was simple. After inspecting the measurements made to the first product types available, it became clear that this ratio was not the same for all references but was the same if the reference was the same. The application calculates these overall weights by inputting the product type reference and the number of wafers. This tool could also insert new measured data if the reference was new and store this data for future calculations.

Costs

Like the last improvement, no relevant costs for ATEP were associated with this implementation. The only cost was the time spent analysing and developing the solution.

Benefits

As mentioned before, the goal of this solution was to remove wastes associated with **transporting**. The amount of travel needed is normalised compared to other clients' products by using this tool. A time study was also done to understand how these improvements were measured in time saved. The predicted travelled distance after improvements was reduced by 83.33%, as shown in Table 4.10, from 9895.2 to 1649.2 m travelled each week.

Table 4.10: Travelled distance in the weighing activity before and after improvements.

Client	Product type	2022	2022 Improved	Var
XFI	MFS	9895.2 m	1649.2 m	83.33%

These improvements also allowed to reduce by 78.92% the time to perform this task, as presented in Table 4.11, from 25.76 to 5.43 annual hours.

Table 4.11: Amount of hours needed to perform the weighing activity before and after improvements.

Client	Product type	2022	2022 Improved	Var
XFI	MFS	25.76 h	5.43 h	78.92%

The objectives of this project were addressed separately, but as had been shown, all three are intrinsically connected. The improvements were measured by a combination of Lean methodologies and time and motion studies.

Chapter 5

Conclusion and Future Works

This project, developed at ATEP, aimed to improve the current logistic processes and maintain its competitiveness in this always-changing market. ATEP competes with other semiconductor industries in the Asian continent, where the cost associated with labour is much inferior. Besides this, several events created a shortage that added pressure to increase production volume. These two factors increase the need and importance of having efficient projects to maintain a competitive cost structure.

5.1 Process Improvement

Through Lean thinking and its methodologies, it was possible to identify activities that did not add value to the end customer and prepare the shipping area for the following months. A prediction model was put in place to define the space requirements for the shipping area at ATEP.

This model showed a lack of space to store productive material, as shown previously, and this was addressed by adding four new shelves identic to the ones already in use resulting in a 50% increase for DNQ products and 64.23% for the rest of the clients.

It also recommended that two packing stations be redesigned, both on and off the workbench, to respond to the change brought by new clients and products.

Finally, the storage of packed material was also addressed by implementing new *rules* to separate each order by client, product type, and the final destination. The final proposed solution considers 30 slots, a variation of 300% when compared to AS IS model.

The organisation and location change of several types of equipment and buffers resulted in a total reduction of 4856 weekly travelled meters for the shipping team.

The consideration of two new types of equipment, an ergonomic improvement of the workstation was possible by reducing certain risk factors associated with specific physically demanding activities.

Removing the need for the operator to distribute the production lots into a larger outer box resulted in a total of 65.62 labour hours saved in 2021 and 61.95 in 2022.

Decreasing the frequency of movements to perform the weighing activity also allowed a predicted decrease from 25.76 annual labour hours to 5.43, representing a 78.92% variation. A motion study was also applied that reduced the 9895.2 m needed to perform this activity by 83.33%.

Although having these measurable results, and most importantly, ATEP now has a way to look at the future and understand how different situations could influence the shipping area, just by adjusting how reality is modelled.

This model also confirmed that the arrival of this new client and products will apply more pressure on the shipping team and the shipping area, so both must be prepared. The gathered data from the time study is saved to ensure that the process does not deviate from its supposed duration.

The continuous improvement mindset should be continuously implemented.

5.2 Future works

The work of identifying inefficiencies and improving processes must be continuous, seeking to daily to achieve operational excellence in the various areas of the company. As such, the organisation must maintain Lean thinking and a continuous improvement mindset, not only in the shipping area but also in other areas.

The model that defined all the space requirements could be even more automated and redefined to maybe, be applied to the Incoming warehouse.

A more in-depth analysis of the ergonomic situation could be implemented to understand more opportunities to improve this situation. Although only considering the packing procedure for productive material, this is not the only material shipped by ATEP, and these processes could also be analysed and studied so that the overall process is improved even further.

Bibliography

Bassi, L. and McMurrer, D. (2005). What to do when people are your most important asset. *Handbook of business strategy*.

Bridger, R. (2008). *Introduction to ergonomics*. Crc Press.

Burkacky, O., Lingemann, S., and Pototzky, K. (2021). Coping with the auto-semiconductor shortage: Strategies for success.

Cardoso, M. (1963). *Métodos, movimentos e tempos de trabalho*. Instituto Nacional de Investigação Industrial.

Daneshjo, N., Rudy, V., Malega, P., and Krnáčová, P. (2021). Application of spaghetti diagram in layout evaluation process: a case study. *Technol. Edu. Manag. Inf. J*, 10(2):573–582.

Dantzig, G. B. (2002). Linear programming. *Operations research*, 50(1):42–47.

De Mente, B., De Neufville, R., and De, S. (1994). *Japanese etiquette & ethics in business*. McGraw-Hill.

Deb, K. and Pal, K. (2004). *Efficiently solving: A large-scale integer linear program using a customized genetic algorithm*. Springer.

Denis, D., St-Vincent, M., Imbeau, D., Jette, C., and Nastasia, I. (2008). Intervention practices in musculoskeletal disorder prevention: a critical literature review. *Applied ergonomics*, 39(1):1–14.

Eiben, A. E. and Smith, J. E. (2015). What is an evolutionary algorithm? In *Introduction to evolutionary computing*, pages 25–48. Springer.

Hales, T. R. and Bernard, B. P. (1996). Epidemiology of work-related musculoskeletal disorders. *Orthopedic Clinics of North America*, 27(4):679–709.

ISO, E. (1999). 14644-1,"cleanrooms and associated controlled environments—part 1: Classification of air cleanliness,". *European Standard*.

Johnson, C. N. (2002). The benefits of pdca. *Quality Progress*, 35(5):120.

Kanawaty, G. (1992). *Introduction to work study*. International Labour Organization.

Karloff, H. (2008). *Linear programming*. Springer Science & Business Media.

Kee, D. and Karwowski, W. (2007). A comparison of three observational techniques for assessing postural loads in industry. *International Journal of Occupational safety and ergonomics*, 13(1):3–14.

Kobayashi, K., Fisher, R., and Gapp, R. (2008). Business improvement strategy or useful tool? analysis of the application of the 5s concept in japan, the uk and the us. *Total Quality Management*, 19(3):245–262.

Lawler, E. L. and Wood, D. E. (1966). Branch-and-bound methods: A survey. *Operations research*, 14(4):699–719.

Liker, J. K. (2004). *Toyota way: 14 management principles from the world's greatest manufacturer*. McGraw-Hill Education.

Lopetegui, M., Yen, P.-Y., Lai, A., Jeffries, J., Embi, P., and Payne, P. (2014). Time motion studies in healthcare: what are we talking about? *Journal of biomedical informatics*, 49:292–299.

Madan, A. and Shaw, M. P. (2012). *The physics and applications of amorphous semiconductors*. Elsevier.

Meyers, F. E. and Stewart, J. R. (2002). *Motion and time study for lean manufacturing*. Pearson College Division.

MicroChemicals (2022). Silicon ingot production process for wafers.

Moen, R. (2009). *Foundation and History of the PDSA Cycle*. Associates in Process Improvement.

Moen, R. and Norman, C. (2006). Evolution of the pdca cycle.

Ohno, T. and Bodek, N. (2019). *Toyota production system: beyond large-scale production*. Productivity press.

Osada, T. (1989). 5s-tezukuri no manajiment shuho (5s-handmade management technique). *Japan Plant Maintenance: Tokyo, Japan*.

Pyzdek, T. (2021). Spaghetti diagrams. In *The Lean Healthcare Handbook*, pages 25–28. Springer.

Ravi, S. (2022). Global semiconductor sales, units shipped reach all-time highs in 2021 as industry ramps up production amid shortage.

Safdarian, A., FOTUHI-FIRUZABAD, M., and Aminifar, F. (2013). Composite power system adequacy assessment based on postoptimal analysis. *Turkish Journal of Electrical Engineering and Computer Sciences*, 21(1):90–106.

Senderska, K., Mareš, A., and Václav, Š. (2017). Spaghetti diagram application for workers' movement analysis. *UPB Scientific Bulletin, Series D: Mechanical Engineering*, 79(1):139–150.

Smith, S. (2014). Muda, muri and mura. *Lean & Six Sigma Review*, 13(2):36.

Sveiby, K. E. (1997). *The new organizational wealth: Managing & measuring knowledge-based assets*. Berrett-Koehler Publishers.

Taylor, F. W. (2004). *Scientific management*. Routledge.

Tompkins, J. A., White, J. A., Bozer, Y. A., and Tanchoco, J. M. A. (2010). *Facilities planning*. John Wiley & Sons.

Wickens, C. D., Gordon, S. E., Liu, Y., and Lee, J. (2004). *An introduction to human factors engineering*, volume 2. Pearson Prentice Hall Upper Saddle River, NJ.

Wijsman, P. J., Molenaar, L., van't Hullenaar, C. D., van Vugt, B. S., Bleeker, W. A., Draaisma, W. A., and Broeders, I. A. (2019). Ergonomics in handheld and robot-assisted camera control: a randomized controlled trial. *Surgical endoscopy*, 33(12):3919–3925.

Wolsey, L. A. and Nemhauser, G. L. (1999). *Integer and combinatorial optimization*, volume 55. John Wiley & Sons.

Womack, J. (2006). Mura, muri, muda. *Jim Womack E-letter*, 7.

Womack, J. P. and Jones, D. T. (1996). Lean thinking, simon and schuster. *New York, NY*.

Appendix A

Rapid Upper Limb Assessment form

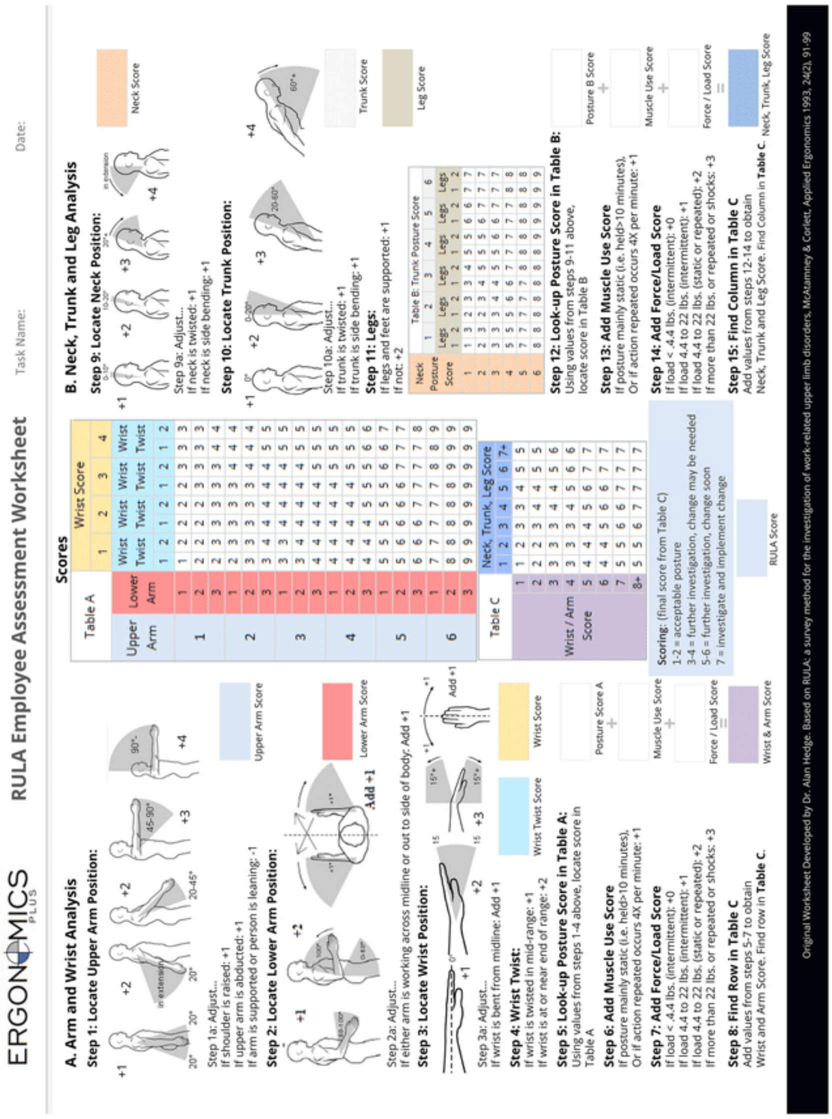

Figure A.1: Rapid Upper Limb Assessment form. Wijsman et al. (2019)

Appendix B

Spaghetti diagrams

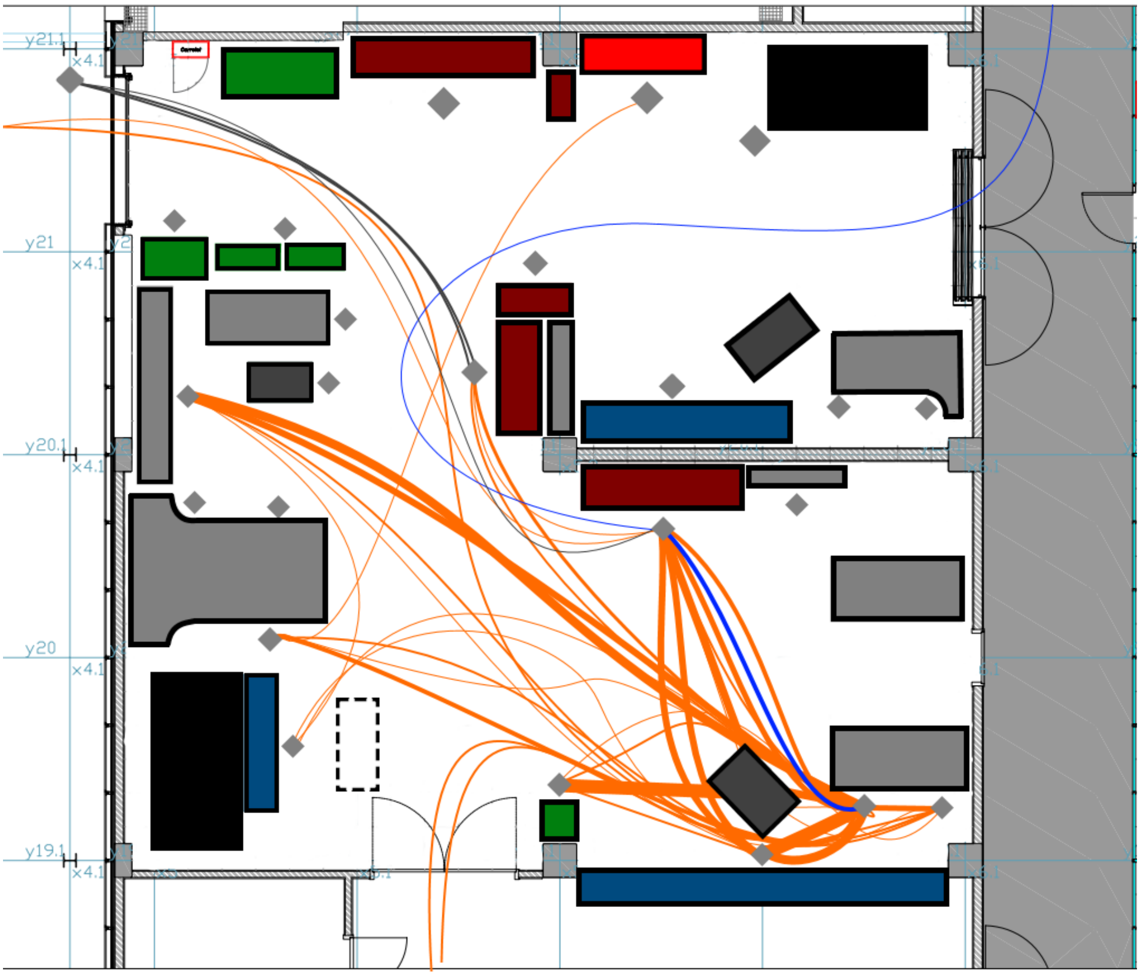

Figure B.1: Spaghetti diagram for Operator 1, representing the initial situation.

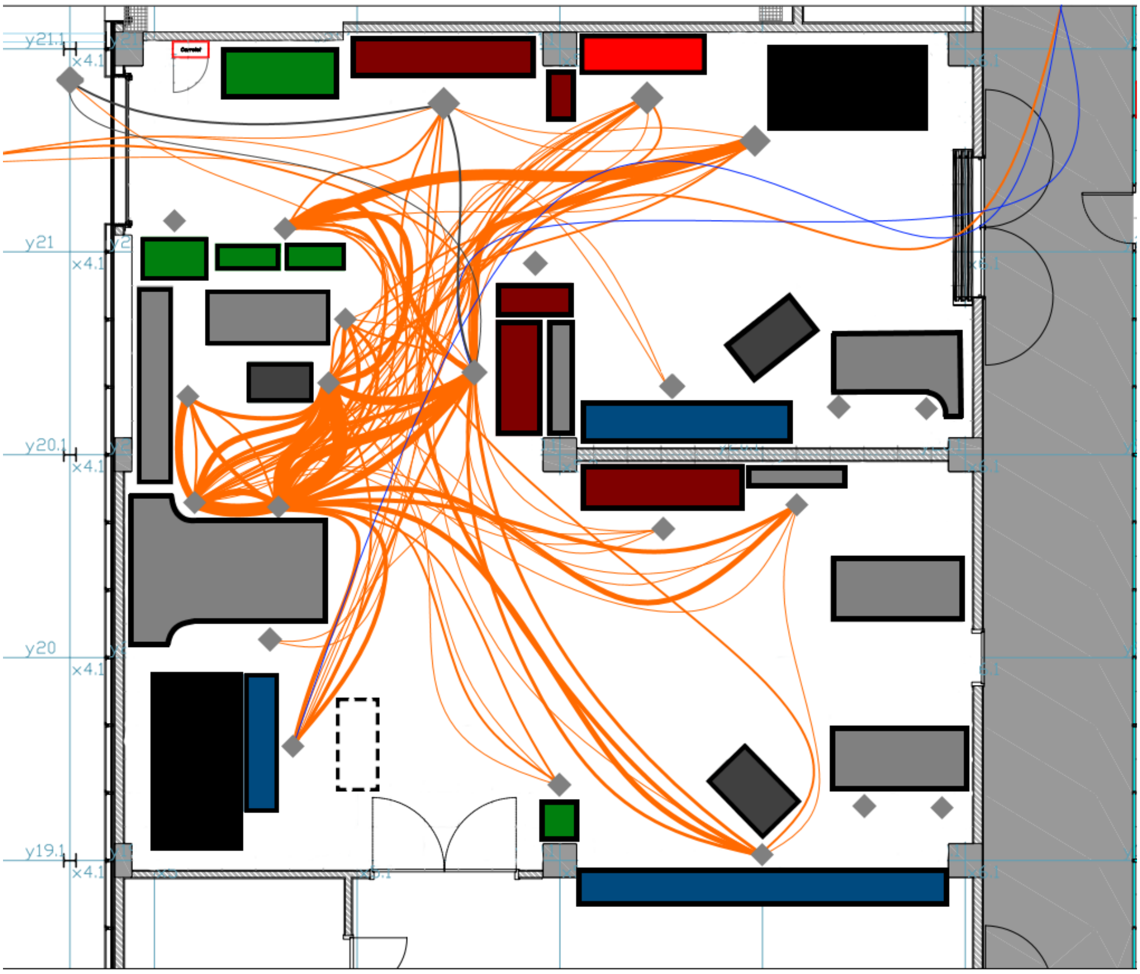

Figure B.2: Spaghetti diagram for Operator 2, representing the initial situation.

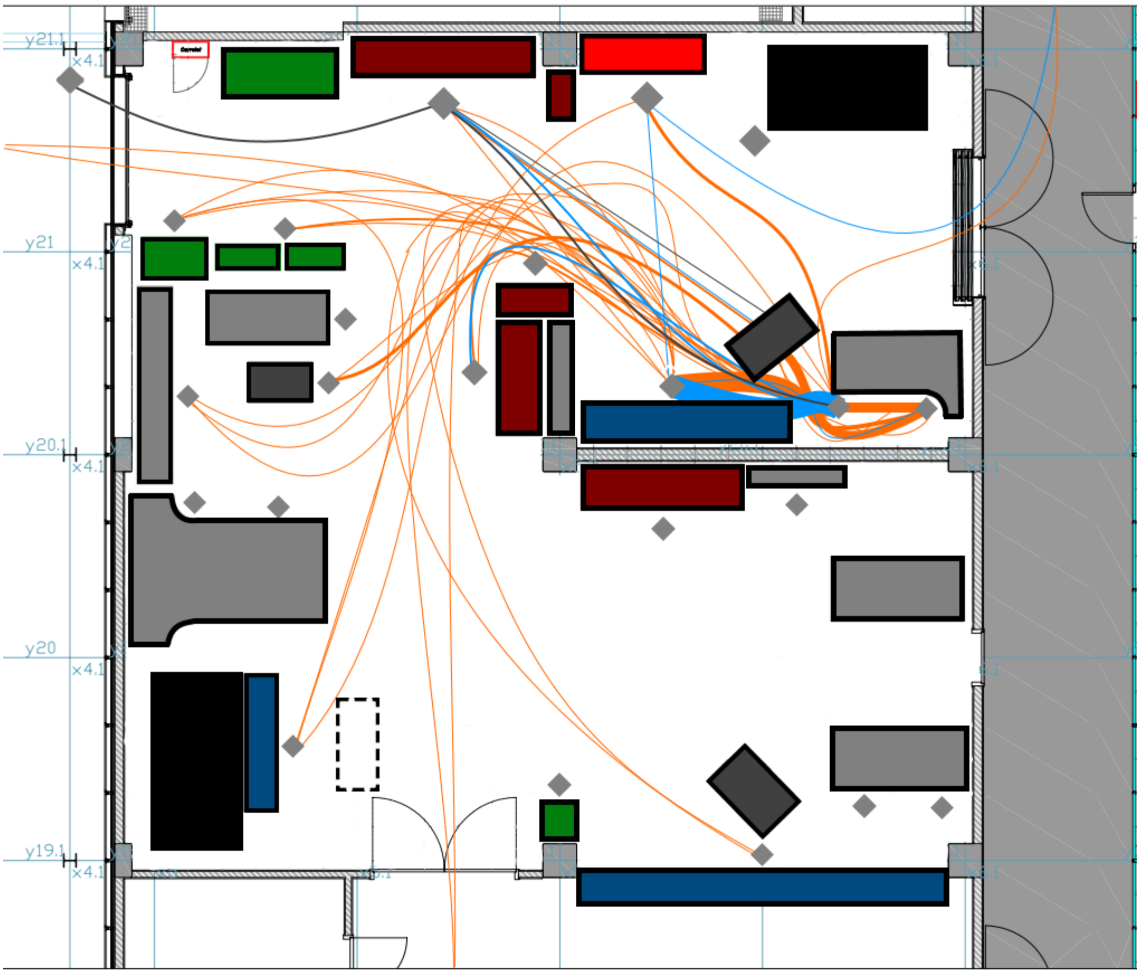

Figure B.3: Spaghetti diagram for Operator 3, representing the initial situation.

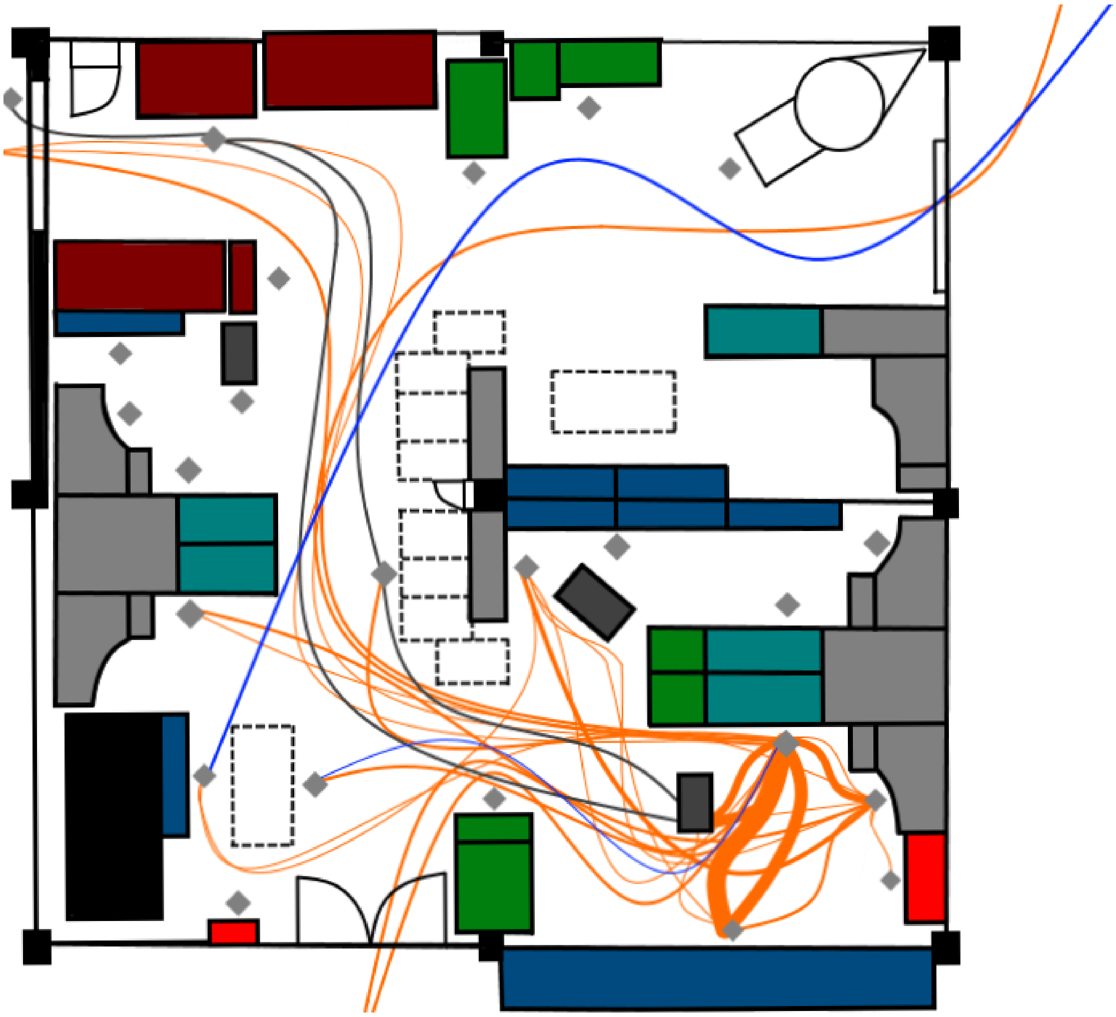

Figure B.4: Spaghetti diagram for Operator 1 TO BE model.

Figure B.5: Spaghetti diagram for Operator 2 TO BE model.

Figure B.6: Spaghetti diagram for Operator 3 TO BE.

Appendix C

Space requirements prediction model

The following chapter explains the model used to predict the space requirements to prepare the shipping area at ATEP for the arrival of new clients and products. The implementation of this model should continue in the future to ensure that this area is capable of meeting customer demand and give insight as to when it is time to improve this area again or change the location, further cementing the continuous improvement mindset.

This model uses confidential information, so no actual values will be shown. Besides explaining the model, an example for the client LTI is also given.

Although this study represented the main reason for producing this model, a continuous improvement mindset was implemented by turning the tool that yielded the results automatically. In other words, the values of the production plan are inputted automatically to ensure that in the future, ATEP could have a way to decide if this area is suitable for performing the desired operations or if it needs any change.

This model was based on the factory's production plan, which was provided in weekly amounts of units shipped for each product type and client until mid-2023. For this example, the values considered as the production plan are presented in Table C.1. These values were randomly created for confidentiality reasons to explain this model since the production plan is not given. This example contemplates only 15 weeks, starting in W1 until W15 since the process is the same for every week.

The input values were the number of individual units for a specific product and client. However, the productive material that reached the shipping area was not just those units but those units inside a specific shipper. So, the number of units in a lot must be converted to units of productive material. The number of units predicted to be shipped for each product type is divided by the conversion factors provided by the Capacity team at ATEP to reach the number of productive material units. These factors are shown in Table C.1, representing the number of units in each shipper.

Table C.1: Example of conversion factors from individual units to shippers for each product type.

Product type	Factor
TR	3000
TB	3900
FOSB	3750

The result of this calculation is presented in figure C.2. These values were rounded into units to represent the actual number of shippers sent each week.

The number of shippers to be shipped could be multiplied by defined factors to distribute these weekly amounts into daily amounts. These factors were created by ATEP internally, and the whole

Week	TR	TB	FOSB
W1	133490	295265	32830
W2	146839	262101	32830
W3	186886	390477	32830
W4	333725	369081	28140
W5	266980	369081	25795
W6	133490	326289	25795
W7	133490	379779	32244
W8	186886	369081	20402
W9	213584	411873	18760
W10	173537	454665	32830
W11	160188	476061	24857
W12	146839	460014	16415
W13	226933	278148	14070
W14	200235	267450	16415
W15	333725	224658	11960

Figure C.1: Production plan example in individual units.

factory uses them to understand the daily capacities better and keep track of clients' orders. An example of these factors is displayed in Table C.2, and do not represent the actual values used by ATEP.

Table C.2: Example of the factors that divide the weekly demand into daily demand.

Product type	Monday	Tuesday	Wednesday	Thursday	Friday	Total
TR	0.2	0.1	0.4	0.1	0.4	1.2
TB	0.4	0.1	0.3	0.1	0.3	1.2
FOSB	0.35	0.1	0.25	0.1	0.4	1.2

The daily amount of units that reach the shipping for every weekday of W1 through W15 are presented in Figure C.3.

Having the amounts of shippers that would be dispatched each weekday, for every week, three different calculations needed to be performed in order to obtain our results. The calculations done to obtain the results are shown next. This method was applied for every product of every client, with some variations due to specific client requirements. To ensure process quality and consistency, almost all the specifications shown in these calculations were decided by ATEP and client requirements.

These specifications meant that the data could be analysed and conclusions drawn by simply controlling reality to be consistent. By fulfilling these *rules*, ATEP should be able to predict these needs in the future and act accordingly, further cementing the continuous improvement mindset.

Several tests were done, and some definitions were altered, that in the end, represented a capable method of predicting reality. These tests comprised computing the daily demand and checking if the results matched reality. These definitions mainly were to product types, like S and D from VSN, that may not reach the outer box capacity. ATEP also defined a safety margin to prepare for demand peaks that could not be predicted.

Week	TR	TB	FOSB
W1	45	76	9
W2	49	68	9
W3	63	101	9
W4	112	95	8
W5	89	95	7
W6	45	84	7
W7	45	98	9
W8	63	95	6
W9	72	106	6
W10	58	117	9
W11	54	123	7
W12	49	118	5
W13	76	72	4
W14	67	69	5
W15	112	58	4

Figure C.2: Production plan example in number of shippers.

C.1 Productive material storage

All clients have specific arrangements that the shipping team must comply with, which define how the materials are displaced on the assigned shelves. The maximum amount of shippers that could be stacked on top of each other is specific for every client's products, and these productive material *towers* are defined as *stacks*. Table C.3 shows the maximum height considered for each product type.

Table C.3: Maximum amount of shippers that can be stacked on top of each other.

Product type	Number of shippers
TR	10
TB	3
FOSB	1

Dividing the number of shippers by this maximum amount gives us the number of stacks for each product, as seen in Equation C.1. However, a full stack occupies the same area as half a stack.

$$Amount\ of\ stacks_{productive\ material} = \frac{Shipper\ amount}{Maximum\ height} \tag{C.1}$$

The area that a single shipper occupies, defined in Table C.4, represents the area a stack will take up.

Table C.4: Area occupied by a single stack of productive material.

Product type	Area
TR	0.12425 m^2
TB	0.0693 m^2
FOSB	0.138 m^2

Week	Monday			Tuesday			Wednesday			Thursday			Friday		
	TR	TB	FOSB	TR	TB	FOSB	TR	TB	FOSB	TR	TB	FOSB	TR	TB	FOSB
W1	9	31	4	5	8	1	18	23	3	5	8	1	18	23	4
W2	10	28	4	5	7	1	20	21	3	5	7	1	20	21	4
W3	13	41	4	7	11	1	26	31	3	7	11	1	26	31	4
W4	23	38	3	12	10	1	45	29	2	12	10	1	45	29	4
W5	18	38	3	9	10	1	36	29	2	9	10	1	36	29	3
W6	9	34	3	5	9	1	18	26	2	5	9	1	18	26	3
W7	9	40	4	5	10	1	18	30	3	5	10	1	18	30	4
W8	13	38	3	7	10	1	26	29	2	7	10	1	26	29	3
W9	15	43	3	8	11	1	29	32	2	8	11	1	29	32	3
W10	12	47	4	6	12	1	24	36	3	6	12	1	24	36	4
W11	11	50	3	6	13	1	22	37	2	6	13	1	22	37	3
W12	10	48	2	5	12	1	20	36	2	5	12	1	20	36	2
W13	16	29	2	8	8	1	31	22	1	8	8	1	31	22	2
W14	14	28	2	7	7	1	27	21	2	7	7	1	27	21	2
W15	23	24	2	12	6	1	45	18	1	12	6	1	45	18	2

Figure C.3: Daily amount of shippers to be sent each day for the considered weeks.

Knowing the number of stacks and multiplying it by the area that it occupies (this value is obtained by calculating the area of the surface touching the shelf[1]) results in the area that a specific product takes up, as presented in Equation C.2.

$$Productive\ material\ occupied\ area = Amount\ of\ stacks \times Shipper\ biggest\ surface\ area \quad (C.2)$$

The area occupied by each type of productive material for every day of each week that resulted from the previous calculations is shown in Figure C.4.

Week	Monday			Tuesday			Wednesday			Thursday			Friday		
	TR	TB	FOSB	TR	TB	FOSB	TR	TB	FOSB	TR	TB	FOSB	TR	TB	FOSB
W1	0.1243	0.7623	0.552	0.1243	0.2079	0.138	0.2485	0.5544	0.414	0.1243	0.2079	0.138	0.2485	0.5544	0.552
W2	0.1243	0.693	0.552	0.1243	0.2079	0.138	0.2485	0.4851	0.414	0.1243	0.2079	0.138	0.2485	0.4851	0.552
W3	0.2485	0.9702	0.552	0.1243	0.2772	0.138	0.3728	0.7623	0.414	0.1243	0.2772	0.138	0.3728	0.7623	0.552
W4	0.3728	0.9009	0.414	0.2485	0.2772	0.138	0.6213	0.693	0.276	0.2485	0.2772	0.138	0.6213	0.693	0.552
W5	0.2485	0.9009	0.414	0.1243	0.2772	0.138	0.497	0.693	0.276	0.1243	0.2772	0.138	0.497	0.693	0.414
W6	0.1243	0.8316	0.414	0.1243	0.2079	0.138	0.2485	0.6237	0.276	0.1243	0.2079	0.138	0.2485	0.6237	0.414
W7	0.1243	0.9702	0.552	0.1243	0.2772	0.138	0.2485	0.693	0.414	0.1243	0.2772	0.138	0.2485	0.693	0.552
W8	0.2485	0.9009	0.414	0.1243	0.2772	0.138	0.3728	0.693	0.276	0.1243	0.2772	0.138	0.3728	0.693	0.414
W9	0.2485	1.0395	0.414	0.1243	0.2772	0.138	0.3728	0.7623	0.276	0.1243	0.2772	0.138	0.3728	0.7623	0.414
W10	0.2485	1.1088	0.552	0.1243	0.2772	0.138	0.3728	0.8316	0.414	0.1243	0.2772	0.138	0.3728	0.8316	0.552
W11	0.2485	1.1781	0.414	0.1243	0.3465	0.138	0.3728	0.9009	0.276	0.1243	0.3465	0.138	0.3728	0.9009	0.414
W12	0.1243	1.1088	0.276	0.1243	0.2772	0.138	0.2485	0.8316	0.276	0.1243	0.2772	0.138	0.2485	0.8316	0.276
W13	0.2485	0.693	0.276	0.1243	0.2079	0.138	0.497	0.5544	0.138	0.1243	0.2079	0.138	0.497	0.5544	0.276
W14	0.2485	0.693	0.276	0.1243	0.2079	0.138	0.3728	0.4851	0.276	0.1243	0.2079	0.138	0.3728	0.4851	0.276
W15	0.3728	0.5544	0.276	0.2485	0.1386	0.138	0.6213	0.4158	0.138	0.2485	0.1386	0.138	0.6213	0.4158	0.276

Figure C.4: Area occupied (in m^2) by each product type in each day for the considered weeks.

Although referring to a specific product, this productive material occupied area could be combined with others to understand the space requirements for this type of material. Summing up the values presented for each day results in the required area to store this client's product types for each day. These values can be seen in Figure C.5.

The highest value considered in these calculations, which in this example was 1.9093 m^2, is the critical value considered a requirement in this study. The same was done for every client, and the results were shown in Table 4.1.

[1] these dimensions were measured

Week	Monday	Tuesday	Wednesday	Thursday	Friday
W1	1.43855	0.47015	1.2169	0.47015	1.3549
W2	1.36925	0.47015	1.1476	0.47015	1.2856
W3	1.7707	0.53945	1.54905	0.53945	1.68705
W4	1.68765	0.6637	1.59025	0.6637	1.86625
W5	1.5634	0.53945	1.466	0.53945	1.604
W6	1.36985	0.47015	1.1482	0.47015	1.2862
W7	1.64645	0.53945	1.3555	0.53945	1.4935
W8	1.5634	0.53945	1.34175	0.53945	1.47975
W9	1.702	0.53945	1.41105	0.53945	1.54905
W10	1.9093	0.53945	1.61835	0.53945	1.75635
W11	1.8406	0.60875	1.54965	0.60875	1.68765
W12	1.50905	0.53945	1.3561	0.53945	1.3561
W13	1.2175	0.47015	1.1894	0.47015	1.3274
W14	1.2175	0.47015	1.13385	0.47015	1.13385
W15	1.20315	0.5251	1.17505	0.5251	1.31305

Figure C.5: Total area occupied (in m^2) by productive material each day for the considered weeks for this client.

C.2 Packing area

After assembling the outer boxes, they are laid down on the floor and organised according to ATEP requirements. These boxes are still empty and are stored until being used. By defining how these boxes are placed, it is possible to calculate the area they should occupy.

By computing the predicted Shipper amount with the capacity of each outer box for that specific product, the number of outer boxes for that product is obtained through Equation C.3.

$$Outer\ boxes\ amount = \frac{Shipper\ amount}{Outer\ box\ capacity} \tag{C.3}$$

The capacity of each of these product types was defined in Chapter 3 and is presented in Table C.5. This Table also contains the area each outer box occupies, which will be used in the following step.

Table C.5: Capacities and occupied area for the considered outer boxes.

Product type	Outer box	Capacity	Occupied area
TR	I1	10	0.154425 m^2
TB	C1	2	0.1521 m^2
	C2	4	0.1521 m^2
	C3	6	0.1521 m^2
FOSB	I2	1	0.28968 m^2

The TR and FOSB product types only consider one type of outer box for its packing procedure, with a capacity for 10 and 1 shippers, respectively.

TB has three outer boxes contemplated for its process: C1, C2 and C3, capable of containing 2, 4 and 6 tray boxes. In these cases, the daily amount of tray boxes (or shippers) is divided by the number corresponding to the maximum capacity of all the outer boxes to find the number of outer boxes needed. If this number is not an integer (in other words, it is not multiple to the outer box capacity), there will be more than one type of outer box used for a single product type. For example, in a hypothetical scenario, 20 tray boxes reach the packing station: dividing 20 by 6 returns 3.33333..., which is not an integer. The closest lower integer to this number is 3, so 3 C3 outer boxes contain 18 shippers. The two tray boxes are then packed in a C1 box, so for 20 tray boxes, 3 C3 and 1 C1 need to be assembled.

The amount of outer boxes for the TR and FOSB product types for each day of every week is shown in figure C.6.

Week	Monday		Tuesday		Wednesday		Thursday		Friday	
	TR	FOSB	TR	FOSB	TR	FOSB	TR	FOSB	TR	FOSB
W1	1	4	1	1	2	3	1	1	2	4
W2	1	4	1	1	2	3	1	1	2	4
W3	2	4	1	1	3	3	1	1	3	4
W4	3	3	2	1	5	2	2	1	5	4
W5	2	3	1	1	4	2	1	1	4	3
W6	1	3	1	1	2	2	1	1	2	3
W7	1	4	1	1	2	3	1	1	2	4
W8	2	3	1	1	3	2	1	1	3	3
W9	2	3	1	1	3	2	1	1	3	3
W10	2	4	1	1	3	3	1	1	3	4
W11	2	3	1	1	3	2	1	1	3	3
W12	1	2	1	1	2	2	1	1	2	2
W13	2	2	1	1	4	1	1	1	4	2
W14	2	2	1	1	3	2	1	1	3	2
W15	3	2	2	1	5	1	2	1	5	2

Figure C.6: Number of outer boxes needed for TR and FOSB product types.

The TB product type was separated from the others for clarity reasons and is shown in figure C.7.

Week	Monday			Tuesday			Wednesday			Thursday			Friday		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
W1	1	0	5	1	0	1	0	0	4	1	0	1	0	0	4
W2	0	1	4	1	0	1	0	1	3	1	0	1	0	1	3
W3	0	0	7	0	0	2	1	0	5	0	0	2	1	0	5
W4	1	0	6	0	1	1	0	0	5	0	1	1	0	0	5
W5	1	0	6	0	1	1	0	0	5	0	1	1	0	0	5
W6	0	1	5	0	1	1	1	0	4	0	1	1	1	0	4
W7	0	1	6	0	1	1	1	0	5	0	1	1	1	0	5
W8	1	0	6	0	1	1	0	0	5	0	1	1	0	0	5
W9	1	0	7	0	0	2	1	0	5	0	0	2	1	0	5
W10	0	0	8	1	0	2	1	0	6	1	0	2	1	0	6
W11	1	0	8	1	0	2	1	0	6	1	0	2	1	0	6
W12	1	0	8	1	0	2	1	0	6	1	0	2	1	0	6
W13	0	0	5	1	0	1	0	1	3	1	0	1	0	1	3
W14	0	1	4	1	0	1	0	1	3	1	0	1	0	1	3
W15	1	0	4	1	0	1	1	0	3	1	0	1	1	0	3

Figure C.7: Number of outer boxes needed for TB product type.

By applying the same concept of stacks seen earlier and knowing their maximum height and the number of outer boxes, the number of stacks could be drawn. Like in the productive material storage calculations, and for the same reasons, this number is rounded up to units, as shown in Equation C.4.

$$Amount\ of\ stacks_{outer\ boxes} = \frac{Outer\ box\ amount}{Maximum\ height} \tag{C.4}$$

Finally, multiplying this amount by the area each outer box occupies results in the area needed around the packing station to house these cartoon boxes, as shown in Equation C.5.

$$Area\ needed\ to\ place\ the\ outer\ boxes = Amount\ of\ stacks \times Outer\ box\ surface\ area \quad (C.5)$$

Implementing both of the previous Equation to our set of data present in figure C.6 and C.7 results in the values displayed in Figure C.8, for the TR and FOSB products.

Week	Monday		Tuesday		Wednesday		Thursday		Friday	
	TR	FOSB	TR	FOSB	TR	FOSB	TR	FOSB	TR	FOSB
W1	0.154425	0.57936	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.57936
W2	0.154425	0.57936	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.57936
W3	0.154425	0.57936	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.57936
W4	0.154425	0.28968	0.154425	0.28968	0.30885	0.28968	0.154425	0.28968	0.30885	0.57936
W5	0.154425	0.28968	0.154425	0.28968	0.30885	0.28968	0.154425	0.28968	0.30885	0.28968
W6	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968
W7	0.154425	0.57936	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.57936
W8	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968
W9	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968
W10	0.154425	0.57936	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.57936
W11	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968
W12	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968
W13	0.154425	0.28968	0.154425	0.28968	0.30885	0.28968	0.154425	0.28968	0.30885	0.28968
W14	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968	0.154425	0.28968
W15	0.154425	0.28968	0.154425	0.28968	0.30885	0.28968	0.154425	0.28968	0.30885	0.28968

Figure C.8: Total area occupied (in m^2) by the outer boxes for TR and FOSB product types.

And for TB product type, the results are shown in Figure C.9.

Week	Monday			Tuesday			Wednesday			Thursday			Friday		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
W1	0.1521	0	0.4563	0.1521	0	0.1521	0	0	0.3042	0.1521	0	0.1521	0	0	0.3042
W2	0	0.1521	0.3042	0.1521	0	0.1521	0	0.1521	0.3042	0.1521	0	0.1521	0	0.1521	0.3042
W3	0	0	0.6084	0	0	0.1521	0.1521	0	0.4563	0	0	0.1521	0.1521	0	0.4563
W4	0.1521	0	0.4563	0	0.1521	0.1521	0	0	0.4563	0	0.1521	0.1521	0	0	0.4563
W5	0.1521	0	0.4563	0	0.1521	0.1521	0	0	0.4563	0	0.1521	0.1521	0	0	0.4563
W6	0	0.1521	0.4563	0	0.1521	0.1521	0.1521	0	0.3042	0	0.1521	0.1521	0.1521	0	0.3042
W7	0	0.1521	0.4563	0	0.1521	0.1521	0.1521	0	0.4563	0	0.1521	0.1521	0.1521	0	0.4563
W8	0.1521	0	0.4563	0	0.1521	0.1521	0	0	0.4563	0	0.1521	0.1521	0	0	0.4563
W9	0.1521	0	0.6084	0	0	0.1521	0.1521	0	0.4563	0	0	0.1521	0.1521	0	0.4563
W10	0	0	0.6084	0.1521	0	0.1521	0.1521	0	0.4563	0.1521	0	0.1521	0.1521	0	0.4563
W11	0.1521	0	0.6084	0.1521	0	0.1521	0.1521	0	0.4563	0.1521	0	0.1521	0.1521	0	0.4563
W12	0.1521	0	0.6084	0.1521	0	0.1521	0.1521	0	0.4563	0.1521	0	0.1521	0.1521	0	0.4563
W13	0	0	0.4563	0.1521	0	0.1521	0	0.1521	0.3042	0.1521	0	0.1521	0	0.1521	0.3042
W14	0	0.1521	0.3042	0.1521	0	0.1521	0	0.1521	0.3042	0.1521	0	0.1521	0	0.1521	0.3042
W15	0.1521	0	0.3042	0.1521	0	0.1521	0.1521	0	0.3042	0.1521	0	0.1521	0.1521	0	0.3042

Figure C.9: Total area occupied (in m^2) by the outer boxes for TB product type.

By adding up all these values, the result is the total area needed around the packing station to store these half-assembled cartoon boxes, as presented in Figure C.10 example.

As done previously, the critical point representing the requirement for the proposed solution is the highest value in this range of data. For the present example, the highest value was 1.34451 m^2, painted in yellow.

The same process was applied to every product considered in this study, that in the end, resulted in the required values shown in Section 4.1.1.

Week	Monday	Tuesday	Wednesday	Thursday	Friday
W1	1.342185	0.748305	0.748305	0.748305	1.037985
W2	1.190085	0.748305	0.900405	0.748305	1.190085
W3	1.342185	0.596205	1.052505	0.596205	1.342185
W4	1.052505	0.748305	1.05483	0.748305	1.34451
W5	1.052505	0.748305	1.05483	0.748305	1.05483
W6	1.052505	0.748305	0.900405	0.748305	0.900405
W7	1.342185	0.748305	1.052505	0.748305	1.342185
W8	1.052505	0.748305	0.900405	0.748305	0.900405
W9	1.204605	0.596205	1.052505	0.596205	1.052505
W10	1.342185	0.748305	1.052505	0.748305	1.342185
W11	1.204605	0.748305	1.052505	0.748305	1.052505
W12	1.204605	0.748305	1.052505	0.748305	1.052505
W13	0.900405	0.748305	1.05483	0.748305	1.05483
W14	0.900405	0.748305	0.900405	0.748305	0.900405
W15	0.900405	0.748305	1.05483	0.748305	1.05483

Figure C.10: Total area needed (in m^2) each day for the considered weeks for this client.

C.3 Packed material

The outer box amount defined previously also allows for the space needed to store the packed material calculation. Most of the outer boxes are designed to fit in a wood pallet without wasting space, so the most efficient way of organising these products was already known for these cases. Since ATEP asked products to be separated by destination, and these product types were already in a situation of optimal placement in a pallet, the notion of a slot was created.

As shown in Figure C.11, these slots have the exact dimensions for almost all of the products, apart from DNQ's product types having a slightly higher height. This notion was created for logistic purposes and to maintain process consistency since the products were already placed in a wood pallet. By analysing the slots capacity for LTI's product types, it became clear that due to its dimensions, it was not efficient to store the packed material in these slots, as it will be addressed when proposing the new layout.

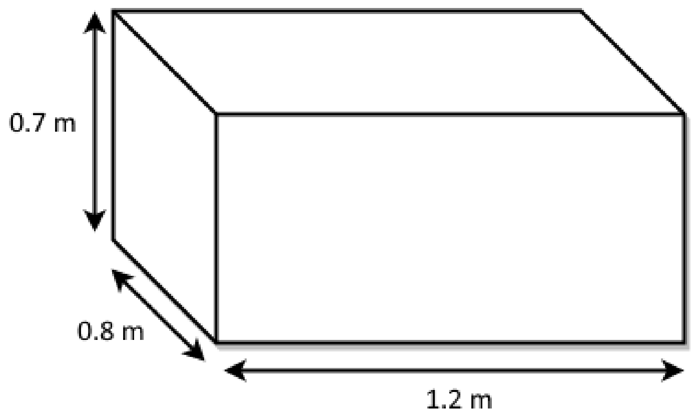

Figure C.11: Slot dimensions (example).

The outer boxes and slot dimensions defined the slots' outer box capacity. By dividing the number of outer boxes for a specific product by their slot capacity, the number of slots for that product could be calculated, as represented in Equation C.6. The values returned by this Equation are rounded to units.

$$Amount\ of\ slots = \frac{Outer\ box\ amount}{Slot\ capacity} \tag{C.6}$$

The slot capacity for each product type was previously determined and is shown in Table C.6. The capacity for C1 and C2 boxes will not be shown since, due to their dimensions, 6 more of either type could be added to a slot with 6 C3 boxes. By analysing Figure C.7, the maximum number of needed C1 and C2 boxes is one, so they do not need to be used.

Table C.6: Number of outer boxes that fit in a single slot.

Product type	Outer box	Number of outer boxes
TR	I1	4
TB	C3	6
FOSB	I2	2

Executing the previous Equation with the values shown in Figure results in the values shown in Figure C.12.

Week	Monday			Tuesday			Wednesday			Thursday			Friday		
	TR	TB	FOSB	TR	TB	FOSB	TR	TB	FOSB	TR	TB	FOSB	TR	TB	FOSB
W1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2
W2	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2
W3	1	2	1	1	1	1	1	1	2	1	1	1	1	1	2
W4	1	1	1	1	1	1	2	1	1	1	1	1	2	1	2
W5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
W6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
W7	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2
W8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
W9	1	2	1	1	1	1	1	1	1	1	1	1	1	1	2
W10	1	2	1	1	1	1	1	1	2	1	1	1	1	1	2
W11	1	2	1	1	1	1	1	1	1	1	1	1	1	1	2
W12	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
W13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
W14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
W15	1	1	1	1	1	1	2	1	1	1	1	1	2	1	1

Figure C.12: Amount of slots needed by every product type and day for the considered weeks.

These slots were then divided by destination with the help of factors given by the Planning team at ATEP and rounded up to units since being shipped to different destinations, representing a different slot. Table C.7 presents an example of these factors.

Table C.7: Number of outer boxes that fit in a single slot.

Product type	Destination	Factor
TR	LTI1	1
TB	LTI2	0.8
	LTI3	0.2
FOSB	LTI2	2

By multiplying these factors by the values obtained in Figure C.12, each destination has its number of slots. The result of this calculation is presented in Figure C.13.

Week	Monday				Tuesday				Wednesday				Thursday				Friday			
	TR	TB		FOSB	TR	TB		FOSB	TR	TB		FOSB	TR	TB		FOSB	TR	TB		FOSB
	LTI1	LTI2	LTI3	LTI2	LTI1	LTI2	LTI3	LTI2	LTI1	LTI2	LTI3	LTI2	LTI1	LTI2	LTI3	LTI2	LTI1	LTI2	LTI3	LTI2
W1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2
W2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2
W3	1	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2
W4	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	2
W5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
W6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
W7	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2
W8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
W9	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
W10	1	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2
W11	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
W12	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
W13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
W14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
W15	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1	1

Figure C.13: Amount of slots needed by every product type and day divided by the several destinations for the considered weeks.

As done before for the other final results, these values can be added, representing the number of slots for each day of every week, as shown in Figure C.14.

Week	Monday	Tuesday	Wednesday	Thursday	Friday
W1	4	4	5	4	5
W2	4	4	5	4	5
W3	5	4	5	4	5
W4	4	4	5	4	6
W5	4	4	4	4	5
W6	4	4	4	4	5
W7	4	4	5	4	5
W8	4	4	4	4	5
W9	5	4	4	4	5
W10	5	4	5	4	5
W11	5	4	4	4	5
W12	5	4	4	4	4
W13	4	4	4	4	4
W14	4	4	4	4	4
W15	4	4	5	4	5

Figure C.14: Total number of slots needed daily for the considered weeks.

Since there are no fixed locations for the storage of packed material, the values obtained for every client must be added to understand which day of which week represents the critical point for the number of slots needed.

Although this study represented the main reason for producing this model, a continuous improvement mindset was implemented by making the tool that yielded the results automatic. In other words, the values of the production plan are inputted automatically to ensure that in the future, ATEP could have a way to decide if this area is suitable for performing the desired operations or if it needs any change.

Although approximate, all the values presented in this example do not represent reality. The importance of this description is not to give insight into how ATEP performs its predictions but to show that by controlling reality to be consistent and implementing several mindsets (PDCA and 5S, for example), it is possible to define requirements and gather essential data, even in an environment like the semiconductor industry.

Appendix D

Linear programming model

As defined in Chapter 2, a model has to be created to solve these types of problems. The first step is understanding the problem and defining the decision variables. Since this problem requires some box with a certain capacity to be filled with smaller boxes, these variables were defined as:

$$x_{ijk} \; with \; i \in \{1,2,3,4,5,6\}, \; j \in \{1,2,3,4,5,6,7,8,9,10\}, \; k \in \{1,2,3\}$$

where i represents the production lots with i boxes, j is the outer box *id* and k is the type of outer box considered.

For $k = 1$ it is a P3 outer (capacity for 48 TB), $k = 2$ a P2 (capacity for 32 TB), and $k = 3$ is a P1 (capacity for 16 TB). For $x_{231} = 4$, it means that 4 lots of 2 tray boxes were allocated in the third P1 outer box, or $x_{412} = 2$ means that 2 lots of 4 tray boxes were to be placed in the first P2 outer box. The total amount of variables summed up to 180.

With the decision variables defined, it is time to look at the restrictions of the problem. There were a total of 10 restrictions considered that characterised this model. The number of restrictions could be reduced by creating a new set of binary decision variables. However, it meant that the problem was no longer linear, and this condemned using another type of engine, which was not ideal. The restrictions considered in this method are shown in Equations D.1 through D.9:

$$\sum_{i=1}^{6}(x_{ijk} \times i) \leq Cap_k \quad \forall \quad j \in \{1,2,3,4,5,6,7,8,9,10\}, \; k \in \{1\} \tag{D.1}$$

$$\sum_{i=1}^{6}(x_{ijk} \times i) \leq Cap_k \quad \forall \quad j \in \{1,2,3,4,5,6,7,8,9,10\}, \; k \in \{2\} \tag{D.2}$$

$$\sum_{i=1}^{6}(x_{ijk} \times i) \leq Cap_k \quad \forall \quad j \in \{1,2,3,4,5,6,7,8,9,10\}, \; k \in \{3\} \tag{D.3}$$

$$\sum_{j=1}^{10}\sum_{k=1}^{3} x_{ijk} = Total \; amount \; of \; lots \; with \; 1 \; TB \quad \forall \quad i \in \{1\} \tag{D.4}$$

$$\sum_{j=1}^{10}\sum_{k=1}^{3} x_{ijk} = Total \; amount \; of \; lots \; with \; 2 \; TB \quad \forall \quad i \in \{2\} \tag{D.5}$$

$$\sum_{j=1}^{10}\sum_{k=1}^{3} x_{ijk} = Total \; amount \; of \; lots \; with \; 3 \; TB \quad \forall \quad i \in \{3\} \tag{D.6}$$

$$\sum_{j=1}^{10}\sum_{k=1}^{3} x_{ijk} = Total\ amount\ of\ lots\ with\ 4\ TB \quad \forall \quad i \in \{4\} \tag{D.7}$$

$$\sum_{j=1}^{10}\sum_{k=1}^{3} x_{ijk} = Total\ amount\ of\ lots\ with\ 5\ TB \quad \forall \quad i \in \{5\} \tag{D.8}$$

$$\sum_{j=1}^{10}\sum_{k=1}^{3} x_{ijk} = Total\ amount\ of\ lots\ with\ 6\ TB \quad \forall \quad i \in \{6\} \tag{D.9}$$

$$x_{ijk} \in \mathbb{Z} \quad \forall \quad i \in \{1,2,3,4,5,6\},\ j \in \{1,2,3,4,5,6,7,8,9,10\},\ k \in \{1,2,3\} \tag{D.10}$$

The first 3 restrictions (Equations D.1, D.2 and D.3) do not let the model exceed the capacity for each of the outer boxes. Equations D.4 to D.9 represent the restrictions that force the system to use all available lots. Lastly, Equation D.10 restricts the model to only using integer variables, as it represents the rule of not dividing lots by two or more outer boxes, i.e., one lot must not be separated.

The last definition needed was the objective function. This, in part, tells the computer what it needs to be calculated. As seen before, the objective of this function is to ensure that the minimal amount of outer boxes is sent, with the minimum amount of empty boxes. A cost perspective was adopted to define this function, so the computer knows that sending an outer box with empty boxes inside should be minimised, and the number of outer boxes.

$$f.o.\ =\ Min\,[\sum_{k=1}^{3}(\sum_{j=1}^{10}(Cap_k - (\sum_{i=1}^{6} x_{ijk})) \times \frac{\sum_{j=1}^{10} x_{ijk}}{Cost_k})] \tag{D.11}$$

The $Cap_k - (\sum_{i=1}^{6} x_{ij1})$ part ensures the model only considers outer boxes with empty spaces to be minimized, since full outer boxes are ideal. By multiplying it with the factor $\frac{\sum_{j=1}^{10} x_{ijk}}{Cost_k}$, that increases as k increases, meaning that a bigger outer box (P1) has a smaller factor that a smaller one (P2 or P3). These factors guaranteed that the computer knew it was better to send a group of lots inside a P1 than divide that group by the P2 and P3 outer for the same number of empty spaces. This factor can be defined as seen in Table D.1.

Table D.1: Cost factors applied in the linear programming model.

k	$Cost_k$
1	50
2	35
3	20

The linear programming model was computed with the help a *MS Excel Macro Enabled* tool, with the *Solver* Add-in help. This Add-in solves considerably simple problems by computing this method using three types of engines: *GRG Nonlinear*, *Simplex LP* and *Evolutionary*. Each with a set of strengths and restrictions.

The *Simplex LP* is the engine that computes the simplex algorithm, developed by Dantzig, although being very fast and reliable, is restricted to linear problems. The *GRG Nonlinear* engine uses a combination of Branch-and-bound and cut planes methods, and although being very quick and efficient, it may not find the optimal solution, by having the possibility of getting stuck in a false optimum slope and not being able to find the real optimal solution.

Finally, the *Evolutionary* engine is based on an inverse metabolic calculation strategy which is based on increasing genetic diversity and screening large populations. The consequent populations will be created with attributes changed randomly, where the *fittest* part of the population is chosen to reproduce the next generation. This allows for solutions to be very close to the optimal zone, but the engine own system often has problems reaching the optimal solution.

To tackle this problem a combination of two engines were considered, by manipulating several *Solver* settings. First, the *Evolutionary* engine was used to position the path to the optimal zone, increasing the chance of reaching an optimal solution in less time and using less computer power. Then, the *GRG Nonlinear* engine quickly finds the best solution in the optimal zone, being, in theory, the best possible outcome.

The operator only needs to provide a list of the lots and its amount of units, press a button and the computer delivers the lots divided by outer box, as asked by the operator.