Productivity Improvement using Lean Tools in a Manufacturing Supplier Automotive Plant

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"The journey of a thousand miles must begin with a single step"
Lao Tzu

Abstract

This project was developed in ERT's production unit 7 with the main objective of increasing productivity in two production lines, by reducing or eliminating tasks without added value for the final customer. In order to do so, the concepts and principles of Lean Manufacturing were used, namely continuous flow and piece-by-piece flow, as well as several Lean tools.

The analysis of the initial situation, found in the two production lines, allowed the identification of several wastes that increased the number of tasks without added value and required a greater number of operators, which caused a decrease in productivity and an increase in costs. This required continuous monitoring of the production lines and the measurement of the times of all the operations. A Lean tool was also used, the Yamazumi charts, which enabled the analysis of the distribution of tasks among the operators and the balancing of the production lines. Then, the proposed improvement solutions were presented, which involved the alteration of the productive processes, changes in the layout of the production lines and the balancing of the tasks by the employees.

In addition, the impact and the result of the implemented solutions were analysed, in particular in the reduction of the number of operators and in the increase of productivity. It was verified that, in both production lines, the proposed solutions improved the productivity levels. Although not all the proposals were implemented, an estimate was also made of the potential results that could be obtained with their implementation.

Aumento de Produtividade através de Ferramentas Lean numa Unidade de Produção de um Fornecedor da Indústria Automóvel

Resumo

O presente projeto foi desenvolvido na unidade de produção 7 da ERT com o principal objetivo de aumentar a produtividade em duas linhas de produção, através da redução ou eliminação das tarefas sem valor acrescentado para o cliente final. Para tal, recorreu-se aos conceitos e princípios do *Lean Manufacturing,* nomeadamente o fluxo contínuo e o fluxo peça-a-peça, assim como a várias ferramentas *Lean.*

A análise da situação inicial, encontrada nas duas linhas de produção, permitiu a identificação de vários desperdícios que aumentavam o número de tarefas sem valor acrescentado e exigiam um maior número de operadores, o que provocava uma diminuição da produtividade e um acréscimo dos custos. Para tal, foi necessário um acompanhamento contínuo das linhas de produção e a medição dos tempos de todas as operações. Recorreu-se também a uma ferramenta *Lean*, os gráficos de *Yamazumi*, que permitiram analisar a distribuição das tarefas pelos operadores e o balanceamento das linhas de produção. De seguida, apresentaram-se as soluções de melhoria propostas que envolveram a alteração dos processos produtivos, mudanças de *layout* das linhas de produção e o balanceamento das tarefas pelos colaboradores.

Além disso, analisou-se o impacto e o resultado das soluções implementadas, em particular na diminuição do número de operadores e no aumento da produtividade. Verificou-se que, em ambas as linhas de produção, as soluções propostas melhoraram os níveis de produtividade. Apesar de nem todas as propostas terem sido implementadas, realizou-se também uma estimativa do potencial resultado que se poderia obter com a respetiva implementação.

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Abbreviations

CAGR – Compound Annual Growth Rate;

ERT1, ERT3, ERT7, ERT8 – Production Units number 1, 3, 7 and 8, respectively;

GDP – Gross Domestic Product;

JIT – Just-in-Time;

KPI – Key Performance Indicator;

OBC – Operator Balance Chart;

OEE – Overall Equipment Effectiveness;

OSKKK – Observe, Standardize, Kaizen 1, Kaizen 2, Kaizen 3;

PK – Production Kanban;

PO – Production Order;

PPH – Parts/Person/Hour;

TPS – Toyota Production System;

WIP – Work-in-Progress;

WK – Withdrawal Kanban.

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1 Introduction

This report describes the project developed in two production lines through the application of Lean Tools carried out within the scope of the master's dissertation in Mechanical Engineering at the Faculty of Engineering of the University of Porto.

The project was carried out at the company ERT Têxtil Portugal, at production unit 7, also referred to as ERT7, in São João da Madeira, Portugal. This project was developed in collaboration between the Continuous Improvement Department and the Production Department. ERT 7 production unit is of medium size, with most sections working in two shifts. However, in case of need or high demand, some sections can work in three shifts.

This chapter introduces the project and the work developed, starting with a presentation of the company. Then, the project is contextualized, indicating its motivations and main objectives. Finally, the methodology followed in the project is indicated, as well as the structure of the dissertation.

1.1 ERT Têxtil Portugal

In 1992, in São João da Madeira, Portugal, ERT Têxtil Portugal was founded, a small company providing services of textile lamination for shoe linings. Over the years, it diversified its business area, until the year 2000, when it expanded into the automotive sector, through the technological knowledge gained from the acquisition of several companies (ERT Grupo, 2022).

Currently, ERT is a Portuguese multinational company, with its core business on the manufacture of automotive interior components. ERT's headquarters are located in São João da Madeira, Portugal, but its presence already extends beyond national borders, with a total of ten production plants spread across six countries, which employ more than 1000 employees (ERT Grupo, 2022). It is already planned the expansion to Mexico and China, in the near future, as it can be seen in Figure 1. ERT has shown a growth in turnover of approximately 15% per year in recent years, which demonstrates the rapid growth it is experiencing, coupled with the strong presence of the automotive industry at European level (ERT Grupo, 2021).

In its strategy, ERT is truly committed in paying attention to the context, the changes in automotive industry and market, and new knowledge.

According to Reports and Data (2022), the global automotive interior materials market size is predicted to increase from the 50 billion dollars registered in 2020, to a total of almost 70 billion dollars by 2030. At the same time, it is expected to register a compound annual growth rate (CAGR) of 3,1% between 2021 and 2030. This growth is related to the expected increase in passenger car sales in the coming years, while the manufacturers are committed to improving car interiors. The vehicle interior is one of the most important factors to the consumers, and that is why the manufacturers are increasingly more focused in the proper material selection for this area (Reports and Data, 2022).

Figure 1 - ERT Group footprint (ERT Grupo, 2021).

In Portugal, according to the Portuguese Manufacturers Association for the Automotive Industry (2022), the automotive components industry represents 0.9% of manufacturing industry companies, which translates into a weight in GDP of 5.2%. In addition, this area directly employs 61,000 workers, which represents 9% of manufacturing employment, according to data collected between 2015 and 2020 (Portuguese Manufacturers Association for the Automotive Industry, 2022). These figures demonstrate the importance of this industry in the Portuguese economy and the reason why it is essential to continuously invest and develop companies to ensure they maintain their strength in an increasingly competitive market.

The increasing national and international competition and market unpredictability highlight the importance of a permanent focus on the development of a culture of innovation, so that ERT group adapts more naturally to an environment with these characteristics. ERT's mission is aligned with this strong need. So, it aims to be a reference in business innovation, and this is what has led the group to implement measures to deliver continuous improvement in the management of their resources, the skills of their people and to use their knowledge in the development of new products. Its vision is that the continuous application of value to the production line maximises the added value of their products, which develops strong partnerships with their customers (ERT Grupo, 2022).

ERT uses different types of technology to manufacture its products, namely, which can also be seen in Figure 2 (ERT Grupo, 2022a):

- Roll Lamination through Flamebond, Hotmelt, Calender, Spraying and Flat Bed;
- Leather, textile, PVC, and foam cutting by press, CNC, or laser;
- Manual and automatic sewing for decorative or functional utilities;
- Covering of plastic parts with textile components;
- RIM - Reaction Injection Moulding.

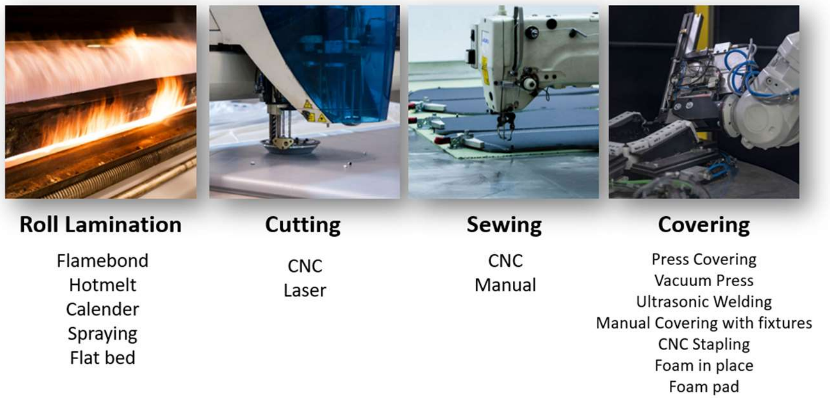

Figure 2 - Technologies used in ERT production plants (ERT Grupo, 2022a).

The different technologies operated by ERT are distributed among the various production plants. The textile lamination is developed in the production units' number 1 and 8, also referred to as ERT 1 and ERT 8, respectively. In the production unit number 7, the technologies used are press, CNC and laser cutting, CNC and manual sewing and the covering of pieces with textile materials. In ERT 3, the production plant number 3, the RIM - Reaction Injection Moulding technology is applied.

To sum up, in its expansion process, ERT has been focused in creating innovation, but also in the increase of its production productivity.

1.2 Project Framework and Motivation

Considering the growth of the automotive industry at a global level, companies are continuously exposed to new projects, in a market which is increasingly competitive. Therefore, it is imperative to maintain and, preferably, improve the competitiveness of companies so that they can outperform the competition and ensuring customer satisfaction. The increase in productivity and quality, coupled with cost reduction, are essential factors to ensure the sustainable growth of a company in a field such as the automotive industry. Lean tools are important and powerful for companies seeking to increase productivity and quality by reducing non-value-added activities. These tools have a much greater impact when implemented all together. However, if the aim of a project is to solve particular problems, companies can choose to apply only a part of the Lean tools.

Initially, the development of this project resulted from ERT having a production line that was in the implementation phase and, as such, presented many inefficiencies. These inefficiencies led the line to present low productivity values, delays in deliveries, which consequently caused an increase in costs. Thus, ERT's intention with this project was to increase productivity by reducing or eliminating waste and no value-added activities, so that this production line could achieve the production objectives established with the client, in the most productive way possible. However, during the project, this production line experienced a substantial reduction in demand by the client and, as such, there was less importance in making significant changes. Therefore, ERT decided to apply the same methodologies to other production line in order to obtain the same results, increase productivity and reduce waste.

ERT objectives for the two production lines are presented in chapter 1.3.

1.3 Project Objectives

The objective of this project is to increase productivity, reduce or minimise waste and reduce activities with no added value in the manufacturing process. The changes made will be based on Lean Tools, which have been used with remarkable success over the last few years in different sectors, and not only in the automotive industry.

Concerning the production line that was in the implementation phase, the specific objectives were to obtain a cycle time lower than the takt time, as well as a reject rate lower than 1.5%.

Regarding the second production line where this project was implemented, the main objective was the same, to increase productivity and reduce waste. However, as it was a production line already in operation, two specific values were established to be improved:

- Increase weekly production from 12000 to 17000 pieces, without resorting to the use of a third shift;
- Reduce the number of employees per shift from 14 to 12.

To achieve the defined objectives in both production lines, a work plan was established, capable of organising and distributing the tasks throughout the time of the project. This plan will be described in chapter 1.4.

1.4 Project Methodology

The project plan carried out to fulfil the proposed objectives is summarized in Figure 3 and it was developed over a period of 18 weeks.

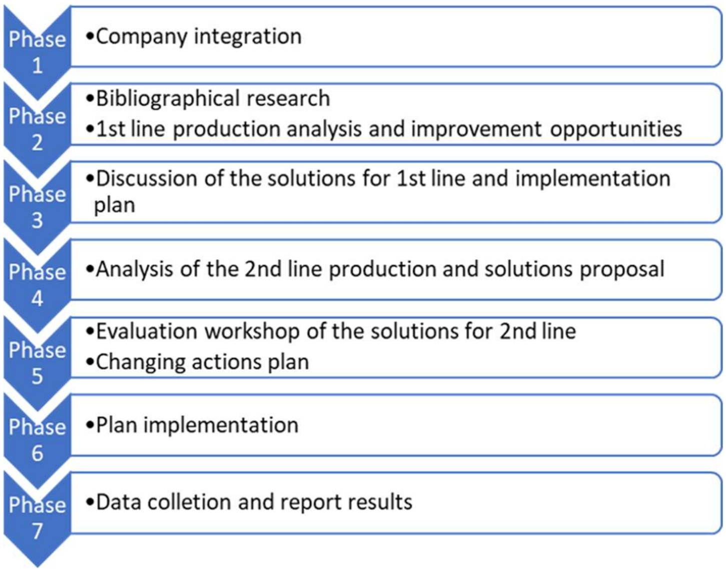

Figure 3 - Plan of the project phases.

Firstly, there was an integration in the company where the project was conducted, so that it was possible to have a more comprehensive view of all the relevant aspects for the work. This phase allowed to understand the general characteristics of the company's production lines, which is essential for the correct execution of the subsequent work.

Secondly, the bibliographical research of methodologies that could be important to apply in the project was made. This research was the basis for Chapter 2 presented in this report. Furthermore, the studied methodologies were the theoretical basis for the implementation of the changes in the production lines, which will be, later, discussed.

During the bibliographical research, the initial production line was analysed in greater detail, to identify the processes with lower productivity and the waste that could be reduced or minimised. Furthermore, improvement opportunities were also sought and analysed, based on what was observed in the day-to-day work.

Thirdly, the solutions that could be implemented to improve the productivity of this production line were analysed and discussed. However, as this production line suffered a sudden reduction in demand, not all the measures that were initially studied were applied.

Fourthly, and associated to the reduction of demand in the first mentioned production line, the project proceeded to another production line. Therefore, it was necessary, once again, to make a detailed analysis of this second production line, in order to understand all the important details, as well as to understand where measures to reduce waste could be applied.

Fifthly, a workshop was held with several people responsible for this production line to discuss and evaluate the measures that could be implemented. In the end of this workshop, a set of changes were established to be executed in the following weeks, with the purpose of achieving the objectives that were made in the beginning of the project.

Sixth, the approved measures, discussed in the workshop, were introduced gradually, in order to understand the improvements that each one brought to the production line.

Finally, in the last weeks, it was collected data on the changes which were implemented, in order to understand if they had the expected effects. In addition, it was at this stage that an evaluation was made of all the measures implemented, to understand what were the results achieved, and also what could be improved for future work.

The execution of the work plan is going to be described throughout this report, according to the structure detailed in chapter 1.5.

1.5 Report Structure

This report is structured in five chapters, which represent the approach taken into this project.

In the first and present chapter, it is made a presentation of the company where the project was carried out, as well as its framework, motivation, and objectives. Furthermore, the methodology followed in the course of the work is also addressed.

The second chapter presents the theoretical framework of the project, whose subjects are essential for the development of the solutions presented, in particular the Lean Manufacturing and Lean Tools are covered.

In the third chapter, a detailed presentation of the project is made. Firstly, the entire production processes are presented as thoroughly as possible, as well as the products manufactured. Subsequently, the main points requiring changes throughout the various stages of the process are indicated.

The fourth chapter presents the proposed solutions in order to achieve the objectives targeted on the production lines, as well as how they were put into practice. It is also made a comparison between the initial situation and the final situation, after the implementation of the improvement solutions.

Finally, in the fifth and final chapter, the main conclusions of the project are presented, as well as the perspectives for future work that could be done.

2 Theoretical Framework

This chapter aims to present the theoretical concepts that have been studied and applied during the project. It starts with an explanation of the origin of Lean Manufacturing, followed by an exposition of its principles, as well as the different types of waste found in production processes. Furthermore, the concepts of just-in-time production and the standardized work are studied, followed by an explanation of the different types of layouts, as well as the concepts behind the balancing of the different production processes of the production lines. A less-known Toyota method called OSKKK is also explained, as it was an interesting tool to apply in this project, as well as the concepts behind Kanban and the ABC Analysis.

2.1 Origin of Lean Manufacturing

The Lean Manufacturing is a concept oriented towards the continuous elimination of waste from processes, reducing the number of tasks without added value. Recently, this concept and its tools have been used with great success within several companies in a wide range of industries. The Lean Manufacturing has its origins in the Toyota Production System (TPS), developed by Taiichi Ohno together with Eiji Toyoda, in the 1950s.

In 1950, Eiji Toyoda visited Ford's Detroit plant, which at the time was the largest and most efficient manufacturing plant. When he returned to Japan, in discussion with Taiichi Ohno, he concluded that mass production established by Ford would not work in Toyota's factories for several reasons. At that time, the car market in Japan was small and very differentiated, which would require having a large capacity to produce smaller quantities of multiple products with different characteristics. Furthermore, the entire Japanese economy and industry was in a very delicate situation due to the post World War II period, which implied that there would be no possibility of making large investments to reach the technological development that the West had, neither to have the capacity to invest significantly in high quantity of stock, which was required in the Ford’s mass production system. Finally, Toyota was also facing fierce competition from other car manufacturers, which forced them to find solutions as quickly as possible in order not to lose their position in the market. Therefore, it was necessary to adapt the western mass production model into a production system capable of serving Toyota's needs and constraints and, this is how the Toyota Production System was created (Dennis, 2015).

The TPS is a unique approach to production and is the basis for the Lean Manufacturing concepts that have dominated industry in recent years. The TPS focuses on maximum waste reduction throughout all stages of the production process, from raw material to finished product. Outside the Toyota universe, TPS is known as Lean, Lean Production or Manufacturing, as these were the terms that became known when the book "The Machine that Changed the World" (Womack, Jones and Ross, 1990) was presented in 1991 (Liker, 2004).

One of the best-known symbols of Lean Manufacturing in modern industry is the Lean House Diagram (Figure 4), which contains the core principles of this concept. The use of the house is intended to express that this philosophy is dependent on the solidity of its foundations, pillars and roof in order to achieve success. In addition, the various elements of the house, which represent the fundamental ideals of Lean, are all related and reinforce each other (Liker, 2004).

When analysing the Lean House, it becomes clear that the objective of Lean Manufacturing, which the roof of the house represents, is to obtain the best quality products, at the lowest cost and with the shortest lead time through the continuous reduction of waste. To achieve these objectives, there are two pillars, Just-in-Time (JIT) and Jidoka. According to Taiichi Ohno (1988), JIT means that, in a flow process, the right parts needed in assembly reach the assembly line at the time they are needed and only in the amount needed. Jidoka means that no defect can be allowed to pass to the next station, which means that if one is detected, the production line must stop, so that it can be corrected as soon as possible (Liker, 2004).

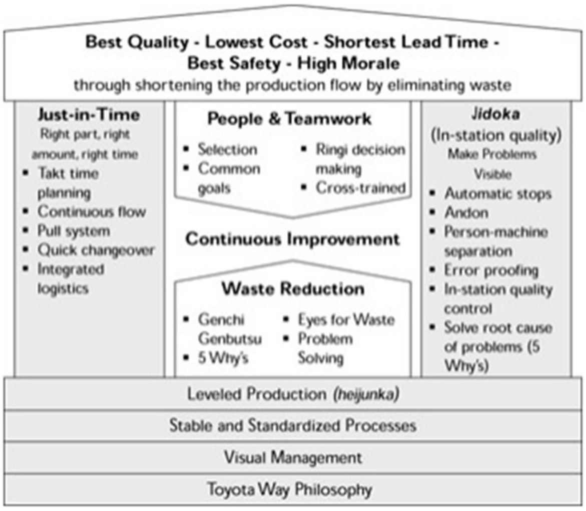

Figure 4 – The Lean House (Liker, 2004).

In the foundations of the house, we have the stability and standardization of processes, levelled production (Heijunka), visual management and the Toyota Way Philosophy. These four concepts are all building blocks to ensure that the pillars and, therefore, the goals of Lean can be achieved (Liker, 2004). Finally, at the heart of the house are the people, continuous improvement and waste reduction that are the key elements in identifying and continuously solving the problems faced on the shop floor (Liker, 2004).

After presenting the origin of the Lean Manufacturing, and one of its best-known symbols, which is the Lean House, the next subject to be explored are the Lean Principles, that are studied in chapter 2.2.

2.2 Lean Principles

According to Womack and Jones (2003), Lean Thinking provides the principles for specifying value and for aligning value-added actions in the best possible way. It also ensures that these actions are performed as efficiently as possible, without interruption.

Lean Thinking is about doing more and more with the minimum resources required, less human effort, less equipment, less time and less space, while ensuring maximum effort is put into reducing waste. According to Womack and Jones (2003), the five principles that are fundamental to the elimination of waste are specifying value, identifying the value stream, the existence of a continuous flow, the pull production system, and the pursuit of perfection in the production processes. These five principles are explained in greater detail in the following topics and can also be found in Figure 5.

Figure 5 - Lean principles (Instituto Lean Management, 2022).

Specify Value

The precise definition of the specification of value is the first fundamental principle for Lean Thinking. Delivering the wrong product in the right way is waste. The first principle of Lean is to correctly establish what the customer wants, specify the value of a product, and be able to deliver it in the most efficient way.

Identify the Value Stream

The value stream is the set of all actions required to deliver a given product to the customer, from raw material to finished product. Identifying the entire value stream is the next principle of Lean Thinking, and it is at this stage that many companies find enormous amounts of waste. This principle is essential to the reduction or elimination of waste in production processes, because if the activities necessary to produce a specific product cannot be properly identified and analysed, it will not be possible to improve or eliminate them.

The value stream analysis allows the identification of three types of activities: activities that add value to the finished product, activities that do not add value but are unavoidable to the process, and activities that do not add value, which should be immediately eliminated.

Continuous Flow

After correctly establishing value, and having identified the value stream, the third principle of Lean is to ensure the continuous flow of products through the various stages of the process.

According to Womack and Jones (2003), processes are more efficient and accurate when products are worked in a continuous flow from raw material to finished product, rather than in larger batches. Thus, it must be ensured that there is a continuous flow on production lines to ensure maximum waste reduction.

Pull Production

The fourth Lean principle concerns Pull Production, which implies that products should only be produced when there is customer demand, in order to make sure that it is the customer that pulls the finished products. This production philosophy drastically reduces stock, compared to Push Production, which produces large quantities of products, that had to be stocked in warehouses before being delivered to the customer.

Perfection

Finally, the last principle of Lean is perfection, which comes after the implementation of the previous four principles. Perfection arises from the constant search for continuous improvement, since the previous principles require the permanent elimination of waste, which implies the systematic reduction of space, time, and defects.

To sum up the principles of Lean, it is the permanent repetition of the first four principles explained previously, that allows a continuous pursuit of a state of perfection for the production processes, where a product is created with the perfect value without waste or non-value-added activities (Instituto Lean Management, 2022). In Chapter 2.3, it will be explained the types of waste and non-value-added activities that are identified in the production lines, which must be eliminated, in order to achieve more Lean production processes.

2.3 Muda

Muda is the Japanese word for waste, which corresponds to all the activities that do not add value to the finished product and that, for this reason, the customer is not willing to pay for. Muda corresponds to all the waiting times, rework, and excess inventory that the customer has no interest in paying for (Dennis, 2015). In most operations, Muda accounts for 95% of the total production time, and is therefore the main reason for the low productivity of production lines (Dennis, 2015).

The main objective of the Lean Manufacturing is to eliminate waste since it corresponds to activities that do not add value to the product. However, to eliminate waste it is first necessary to identify it. According to Taiichi Ohno (Dennis, 2015), the seven types of waste that have been identified in Lean Manufacturing are the following:

- Motion**:** Motion waste refers to the unnecessary movements that the operator must make, which do not add value to the product. This type of waste can be related to poor ergonomics of the workstation, or poorly optimised layout of the production line, incorrect order of operations, and has an impact in the productivity, quality, and safety of operations (Kaizen Institute, 2015) (Dennis, 2015).
- Waiting**:** Waiting waste occurs when there is some sort of waiting time for an operator, or machine, which may be due to excessive work-in-progress (WIP), defects requiring rework or material shortages, caused by either a stoppage in production or a machine to finish processing a part (Kaizen Institute, 2015) (Dennis, 2015). If an operator has waiting times, it will cause delays in the production process, which increases the lead time, that is a very important indicator in Lean Manufacturing (Dennis, 2015).
- Conveyance**:** Conveyance waste refers to the excessive product movements derived from inefficient workstation layout or the movement of large batches between workstations. Transportation is a necessary waste, since products need to be transported within the plant, but it can always be minimized, as it does not add value to the finished product (Dennis, 2015). The only type of conveyance that adds value is the transportation in the direction of the customer (Kaizen Institute, 2015).
- Correction**:** Correction is related to the need to correct and eliminate defects that appear in products throughout production. Defects require rework or a repetition of the work, which reduces the productivity of the production line and, therefore, is something that the client is not interested in paying for (Dennis, 2015).
- Overprocessing**:** Overprocessing is a type of Muda that consists of doing more than is required by the customer, which means that time and resources are being wasted on actions and processes that the customer is not willing to pay (Kaizen Institute, 2015).
- Overproduction**:** Overproduction is the production of products that have not been ordered by the customer, or in a greater quantity than what is needed, and, therefore, cannot be immediately sold and will generate a large quantity of stock (Kaizen Institute, 2015). According to Taiichi Ohno, overproduction is the cause of much of the other types of waste, so if it is avoided, great progress is made towards the goal of minimising waste.
- Inventory**:** Inventory waste refers to all raw materials, WIP and finished product that is stored unnecessarily throughout all stages of the production process. This excess inventory is related to the lack of a continuous flow and the disconnection between demand and production, meaning the lack of a pull production (Dennis, 2015).

To summarize, the understanding of the seven types of Muda is one of the first crucial steps, when analysing a production line, because to adapt the production processes and to eliminate waste, it is necessary to correctly recognize what types of waste are present.

2.4 Just-in-Time Production

JIT Production, originated at Toyota Motor Company by Taiichi Ohno, aims to eliminate all tasks without added value, making production lines lean, with the ability to adapt to fluctuations in customer demand (Imai, 1997). JIT enables costs to be dramatically reduced, products to be delivered at the right times and therefore increases the company's profits (Imai, 1997).

JIT is supported by a set of principles, concepts and tools that enable a company to produce the right quantity at the right time, according to customer demand. This method enables a company to produce products in smaller quantities, with shorter lead times and in the time desired by the customer (Liker, 2004). The most important concepts to support this system are takt time, one-piece-flow, pull production, U-shaped cells, and setup reduction, which are explained below (Imai, 1997).

Takt Time and Cycle Time

Takt time indicates the demand frequency, which represents how frequently a product should be made, and can be calculated by the equation (2.1) (Baudin, 2002).

$$Takt\ Time = \frac{Total\ Available\ Production\ Time}{Customer\ Demand} \tag{2.1}$$

This value represents the pulse of the market and should be known by everyone in the company, since it is the theoretical value that indicates how long it should take to produce a part in each process (Imai, 1997).

Cycle time represents the time it takes to produce a product in each process, which is different from takt time (Instituto Lean Management, 2022). However, the aim of JIT is to bring takt time and cycle time as close as possible together, since to achieve continuous flow in one-piece flow it is necessary for each process to work at takt time pace (Dennis, 2015).

Pull Production

Pull production indicates that nobody should produce a product unless there is a request from the customer (Liker, 2004). In other words, production starts when a customer order arrives, in contrast to push production, in which production is made to stock even when there is no customer order. The pull system allows the reduction of WIP, stock in warehouse and lead time, because everything that is made is to be deliver to the costumer, as soon as it is possible (Liker, 2004).

One-Piece Flow

In pull production, all the processes must be organised so that the parts flow through the workstations in the order in which the processes should be carried out. After the processes are organised, the next objective is to start the one-piece flow, which allows only one part to flow from process to process (Sekine, 1992). This method reduces lead time and inventory between workstations, as well as making it easier to identify quality problems, because a problem in one process is identified in the following process (Imai, 1997).

In conclusion, only these three concepts of the JIT production were addressed in the present chapter, as they were the most important to the project developed. In chapter 2.5 it will be explained the importance of standardized work and the types of standardized documents that were made, in the course of the project.

2.5 Standardized Work

According to Dennis (2015), standardized work is the safest, easiest and most effective way to do a job. At Toyota, the purpose of standard work is to establish a basis for improvement and is therefore continually changing. Standardized work is a tool to develop, confirm and improve a process. A process is a set of steps with a clearly defined goal.

Pascal Dennis (2015) identified seven major benefits in the implementation of Standardized Work, which are listed and explained below:

- Process Stability: Stability allows for the continuous repetition of the desired objectives, in terms of productivity, quality, cost and lead time, among others;
- Clear Stop and Start Points for Each Process: These points associated to the Takt Time knowledge allow an easier visualisation of how the production process is;
- Organisational Learnings: standard work ensures that know-how is preserved, even when more experienced operators leave;
- Audit and Problem Solving: standard work allows you to analyse the current situation and identify problems;
- Employee Involvement: the operators who help in the development of the standard work are, therefore, able to identify improvements to avoid errors;
- Kaizen: standard work is the basis for the continuous improvement of processes;
- Training: standardized work provides a basis for operator training and learning.

There are three charts that can be used as tools to analyse and define processes and identify improvements, these are Production Capacity Chart, Standardized Work Combination Table and Standardized Work Analysis Chart, which are analysed below (Dennis, 2015).

Production Capacity Chart

The Production Capacity Chart allows the capacity of a process to be determined and bottlenecks to be identified, as manual and machine times are entered. The capacity is calculated using the equation (2.2) (Dennis, 2015):

$$Capacity = \frac{Operational\ Time\ per\ Shift}{(Process\ Time + Setup\ Time/interval)} \tag{2.2}$$

Standardized Work Combination Table

The Standardized Work Combination Table indicates the process elements and their sequence, the time spent on each, operator and machine time, and the interactions between operators and machine or between operators (Dennis, 2015).

Standardized Work Analysis Chart

The Standardized Work Analysis Chart allows you to analyse ways to optimise the layout and train the operators, as it contains the work layout and process steps and their times (Dennis, 2015).

To sum up, the standardized work allows the documentation of the production processes and perceive how they are executed. This documentation can be very useful in the integration and training of ERTs operators.

2.6 Layout

Over the past years, several types of layouts for production lines have been studied and analysed, including functional layout, process layout and cell layout. These three layout types have different characteristics which will be analysed in the current chapter. In Figure 6 it is possible to see an example for each of these types of layouts.

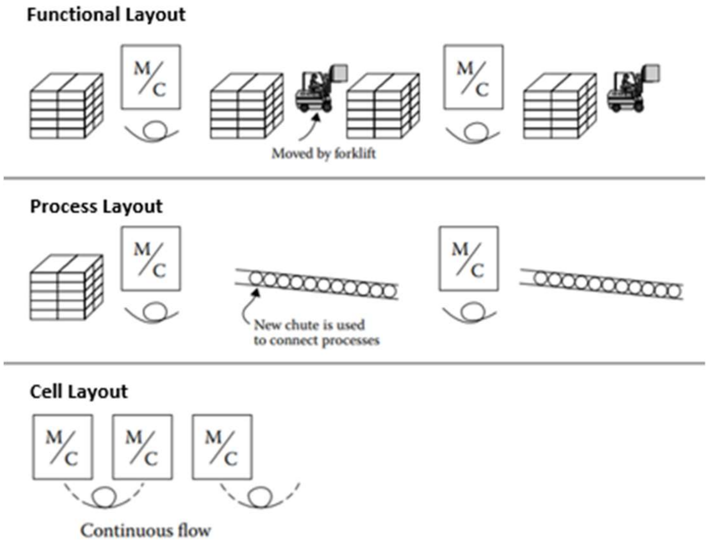

Figure 6 - The three layout types (Dennis, 2015).

The Functional Layout, with island workstations, is normally associated with the production of large batches, which are transported between workstations by forklifts. This type of layout causes a large amount of WIP, high lead time and the appearance of conveyance waste (Dennis, 2015) (Kaizen Institute, 2015).

The Process Layout, a set of connected islands, corresponds to a sequence of processes that are connected by a belt, in which small batches are produced at each workstation (Kaizen Institute, 2015). This type of production lines allows a reduction in WIP and lead time in comparison to the functional layout, but even so it is still not capable of achieving the continuous one-piece flow that the Lean Manufacturing seeks to achieve (Dennis, 2015).

The Cell Layout is a set of several sequential workstations that ensure a continuous one-piece flow. Inventory and WIP between processes are non-existent, and as soon as a part is finished at one workstation it immediately moves on to the next one (Kaizen Institute, 2015). This type of layout substantially reduces WIP and lead time, as well as ensuring continuous quality feedback throughout the process (Dennis, 2015).

In conclusion, the ideal layout in a production line is the cell layout, as it allows a continuous one-piece flow of the pieces produced. This is one of the principles promoted by Lean Manufacturing.

2.7 Line Balancing

The Operator Balance Chart (OBC) or Yamazumi Board is a graphical tool that helps in creating a continuous flow in processes with multiple operators and steps. The OBC uses vertical bars to represent the total working time of each operator, which helps in distributing the tasks among the different operators (ERT Grupo, 2020). This distribution is important for reducing the number of operators because it allows the entire production line to be balanced. Balancing allows all stations to have approximately the same process time, and as close to the takt time as possible, to ensure that it is producing according to customer demand (Lean Enterprise Institute, 2022). The OBC is composed of two axes, the horizontal axis concerns the process operators, and the vertical axis represents time. In addition, a horizontal line representing the takt time value, which is the main target in balancing, is also inserted (Lean Enterprise Institute, 2022). Figure 7 shows an example of an Operator Balance Chart or Yamazumi Board.

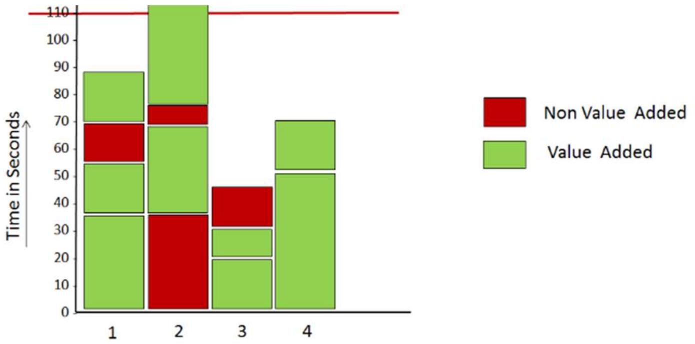

Figure 7 – Example of an Operator Balance Chart or Yamazumi Chart (Muda Masters, 2015).

The theoretical minimum number of operators to ensure the production of the desired number of parts on a production line is given by Equation (2.3) (Baudin, 2002).

$$Number\ of\ Operators = \frac{Total\ Work\ Content}{Takt\ Time} \tag{2.3}$$

Sometimes the number of operators needed on a production line is a fraction, so there is a set of guidelines depending on the value of that fraction, which are described in Table 1.

Table 1 - Guidelines to determining the number of operators (Dennis, 2015).

Fraction of operators	Guideline/Target
< 0.3	Do not add extra operator. Further reduce waste and incidental work (avoidable nonvalue adding activities).
0.3 – 0.5	Do not add extra operator yet. After two weeks of operation and kaizen, re-evaluate whether enough waste and incidental work can be removed.
> 0.5	Add an extra operator if necessary and keep reducing waste and incidental work to eventually eliminate the need for that operator.

To sum up, due to its characteristics, the OBC or Yamazumi chart is a helpful tool to balance the tasks by the operators of a production line. It is also a visual tool, which is easy to understand by everyone in a short time.

2.8 Spaghetti Diagram

The Spaghetti Diagram is a tool for determining the path and distances travelled by a product or an operator along a value stream (Lean Enterprise Institute, 2022). This tool is extremely useful as it allows the entire route along the production line to be analysed and opportunities for improvement sought. This diagram can provide the necessary data for a layout change, which may allow the reduction of movements and transports without added value in the finished product. Figure 8 is an example of a Spaghetti Diagram.

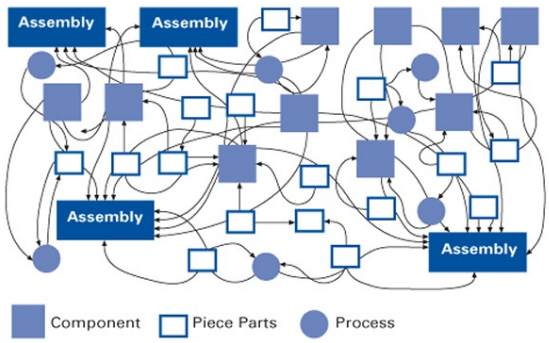

Figure 8 – Example of a Spaghetti Diagram (Lean Enterprise Institute, 2022).

This tool can help the improvement of layouts, which is one of the subjects considered in OSKKK method, that is studied in chapter 2.9.

2.9 OSKKK – Observe, Standardize, Kaizen 1, Kaizen 2, Kaizen 3

OSKKK is a lesser-known Toyota method, which stands for observe deeply, standardize, kaizen of flow and process, kaizen of equipment and kaizen of layout (Lane, 2011).

The first step, in this tool, is the observation of all operations in a process. Different operators should be observed and analysed at the various workstations, to see where there is a lack of standardization, and where this affects quality and productivity. Furthermore, the origins of variations should be identified, namely in the flow of information and the flow of materials (Perez, 2013).

The second step is the standardization of operations and movements, ensuring their optimal sequence throughout the process. This stage ensures that at all points in the process flow follow a standard methodology, which allows operators to work according to the established standards (Perez, 2013).

The third step is kaizen of flow and process and involves understanding the process flow and the material flow through the various operations. This step ensures that material flow at workstations is improved, as all non-value-added time in the final product is identified. It is also at this stage that we try to reduce or eliminate those times that the customer has no interest in paying for (Perez, 2013).

The fourth stage is related to kaizen of equipment and consists in trying to improve and reduce the cycle times of the machines and operators, and also to simplify the processes. Furthermore, it is in this stage that one seeks to understand the workload of the operator compared to the cycle times of the machine, as well as to match them as much as possible (Perez, 2013).

Finally, the fifth stage concerns kaizen of layout, and this is where the layout of the production line is changed to ensure that process improvements are made. The layout changes should ensure that all Lean principles are implemented to eliminate or minimise non-value-added tasks. In addition, new layouts should improve the ratio between machine and operator cycle time (Perez, 2013).

The kaizen steps in the OSKKK method are ordered in order of effectiveness and from least to most costly to implement (Lane, 2011).

2.10 Kanban

The Japanese word Kanban, which means card, has become a synonym for demand scheduling. This tool was introduced by Taiichi Ohno at Toyota to control production between processes and to implement JIT in the various manufacturing plants (Gross and McInnis, 2003). Initially

Toyota used Kanban to reduce costs and control machine utilisation. Kanban allows not only to reduce WIP between processes and to reduce inventory costs, but also to identify continuous flow problems and improvement opportunities (Gross and McInnis, 2003).

Kanban planning provides operators with a visual signal of when to produce and how much, since the aim is to produce according to what is actually consumed in the process, not by predicting what will be consumed. Furthermore, the Kanban rules imply that it is necessary to provide operators with information on what to do and who to communicate with when process problems occur (Gross and McInnis, 2003). Kanban has several benefits, including inventory reduction, improved flow, prevention of overproduction, control at the operations level, visual planning and process control, improved response to change, reduced risk of stale inventory and increased ability to manage the supply chain (Gross and McInnis, 2003).

The Kanban is an instruction for withdrawing products from the preceding process and producing the quantity that has been withdrawn. Thus, there are two types of Kanban: Production Kanban (PK) and Withdrawal Kanban (WK) (Dennis, 2015). The Production Kanban specifies the kind and quantity of product that the upstream process (supplier) must produce (Dennis, 2015). The Withdrawal Kanban is the order for withdrawing the reference. It is used between processes within a site to instruct the internal supply team to pick up the parts from upstream. In other words, it specifies the kind and quantity of product that the downstream process (customer) may withdraw (Dennis, 2015).

A Kanban system consists of a set of cards that are exchanged between processes, which communicates to the preceding process what and how much it should produce and tells the subsequent process what parts are needed. The products and parts of a process should always travel with Kanban. In a process controlled by Kanbans, the production should always follow these rules (Dennis, 2015): only produce products to replace the products consumed by its customer and only produce products based on the signals sent by its customer.

2.11 Key Performance Indicator (KPI)

The industry contains many processes and equipment that need to be controlled to ensure maximum plant productivity. Key Performance Indicators (KPIs) are mainly quantitative information, which allow assisting the control and planning of the plant, through this information. KPIs can be used to identify opportunities for improvement, low productivity, quality, and availability problems, among others. In addition, they can be applied to individual pieces of equipment, sub-processes, or entire plants. Thus, KPIs are crucial in measuring the performance and progress of the processes concerned, in as many different areas as possible (Lindberg, et al., 2015).

According to Richardson and Richardson (2016), KPIs can be divided into two categories: lagging indicators and leading indicators. Lagging indicators are result-oriented, as they appear after something has been done. These KPIs are historical in nature, as they are a reaction to something that happened earlier in a process. Leading indicators are tracking right in the process, which gives a real-time measure of what is happening. These indicators allow you to see whether the process is going according to plan, or whether there is any kind of problem affecting production (Richardson and Richardson, 2016).

One of the most common KPI used to measure manufacturing processes is the Overall Equipment Effectiveness (OEE). OEE focus on how effectively a manufacturing operation is performed and is measured by multiplying three separate components. These components are availability, performance, and quality, and each of them can be targeted for improvement (Stamatis, 2010). The availability represents the percentage of scheduled time that the operation is available to produce parts. The performance represents the actual speed of the operation in comparison with the designed speed. Lastly, the quality is the percentage of good units produced of the total units (Stamatis, 2010).

2.12 ABC Analysis

Pareto's law was developed in the 19th century by an Italian economist called Vilfredo Pareto. This analysis, also called the 80/20 rule, is a concept which indicates that most problems, approximately 80% of them, are usually caused by a small number of sources, about 20%. One aspect to take into consideration, when applying this concept is that the 80/20 ratio should not be taken literally, because it is only indicative that the majority of the results are often derived from a minority of inputs (Powell and Sammut-Bonnici, 2015).

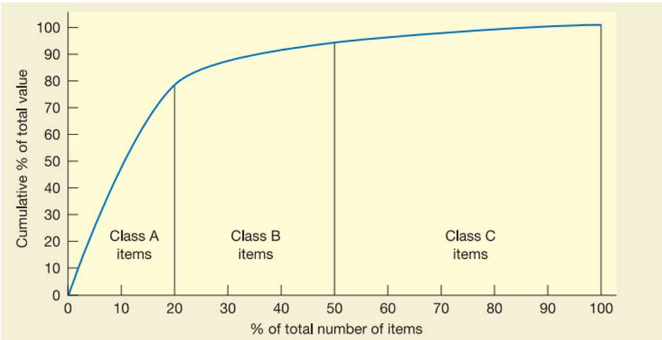

Figure 9 - Pareto Curve and ABC Analysis (Slack, Chambers and Johnston, 2010).

ABC analysis is a classification method based on the Pareto Law, which divides products into 3 classes (A, B and C) (Baudin, 2002). Similar to this law, the ABC analysis defines that in a population of products, there are a reduced number of products, around 20%, which represent 80% of the total demand. These products belong to Class A and are the ones with the greatest importance. Then, the products in Class B, of intermediate importance, represent approximately 30% of the products and account for 15% of total demand. Finally, Class C concerns the remaining 50% of products whose representation in demand is only 5% and, therefore, are considered of low importance (Muller, 2003). Figure 9 is an example of an ABC Analysis and a Pareto Curve.

3 Analysis of the Initial Situation

This project focuses on two production lines and, to start with, it was necessary to observe the various steps of the production process on the shop floor. In the present chapter, the initial situation found is described, so that it can be understood how the work is carried out at the various workstations. Moreover, the analysis of the initial situation of the two production lines where this project will take place is an essential step in identifying the main problems.

3.1 Production Line 1

This project started at the production line that is internally called "MLA" and will be identified from now on as production line 1. This production line produces different products for a single customer, which correspond to a different set of internal references. In addition, these products need to go through an ordered set of processes before being delivered to the customer according to the customer's specifications. In chapters 3.1.1 and 3.1.2 it will be presented the initial situation found in production line 1 in relation to the products produced and the various stages of the production process.

3.1.1 Products Manufactured

On production line 1, are produced 13 products, corresponding to 13 different references, which differ essentially in dimensions and in the number of velcros that need to be applied. Figure 10 shows a set of finished products ready to be delivered to the customer.

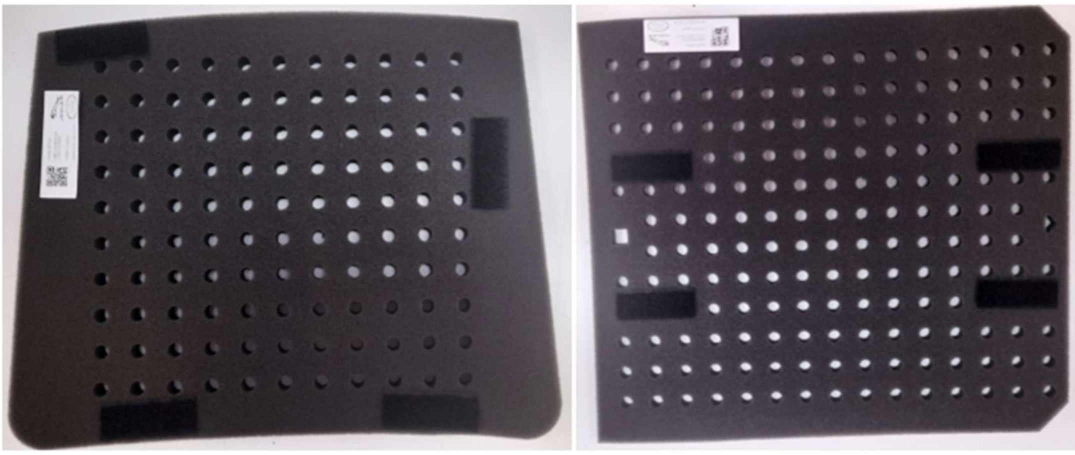

Figure 10 - Example of two references of finished product.

These products are produced from the same raw material, a foam that is supplied to the company in the form of a roll. Although the raw material is the same, there is a difference between the various products. Ten of the products are made of a foam with a thickness of 10 mm and the other 3 products use another with a thickness of 15 mm. This difference in thickness is not a relevant aspect for this project since it does not cause changes in the production process of the products. As shown in Figure 10, the main differences between the products are the dimensions and the number of velcros. The number of velcros in the products varies between 2 and 4, depending on the reference in question. Finally, a label must be applied to all the references produced. Table 2 shows the dimensions of the various products and the number of velcro ribbons that must be applied to each one.

Table 2 - Dimensions, thickness, and number of velcros for the references produced.

ERT Reference	Dimensions [mm]	Thickness [mm]	Number of Velcro
C19032AA01B	314 x 116	10	2
C19032AB01B	265 x 383	10	4
C19032AC01B	350 x 115	10	2
C19032AD02B	300 x 242	15	4
C19032AE01D	307 x 92	10	2
C19032AF02D	248 x 205	15	4
C19032AG01C	344 x 110	10	2
C19032AH02B	280 x 243	15	4
C19032AI01B	260 x 91	10	2
C19032AJ01B	340 x 274	10	4
C19032AO01A	378 x 262	10	4
C19032AP01A	367 x 355	10	2
C19032AQ01A	314 x 273	10	4

3.1.2 Production Process

Production line 1 can be considered a pull system because the operators only start production when there is a production order (PO). This PO contains all the necessary information to produce the item indicated in it. A PO indicates the item to be produced and its quantity, as well as the consumption of raw material and the quantity and type of components required for that production. Furthermore, the production order indicates the order and type of operations that must be performed to transform the raw material into the finished product. An example of a production order is shown in Annex A.

After the issue of the production order, on production line 1 there are three distinct processes: press cutting, drills removal and application of velcros and label, which are composed by several stages. The various processes and their stages will be analysed and described throughout this chapter. Figure 11 shows the process flow of the production line 1.

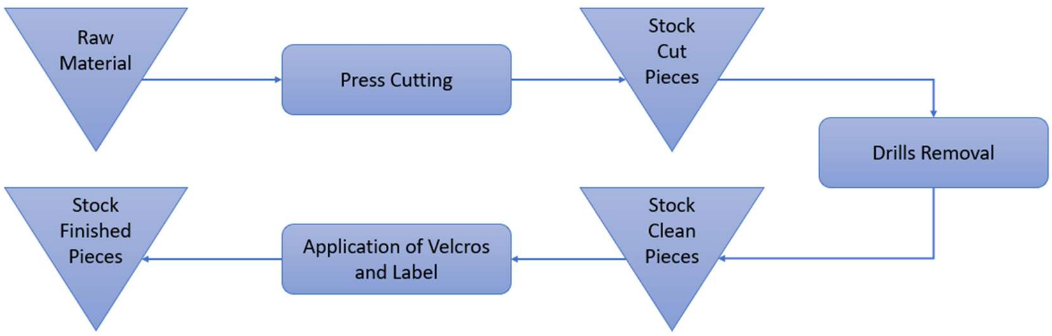

Figure 11 - Process Flow of Production Line 1.

Raw Material

The raw material for this production line is a foam that is supplied to the company in the form of a roll, and there are two references, whose only difference is the thickness. When these rolls are delivered, they are stored in ERT7's raw material warehouse until a production order is launched. When the PO is launched, the press operator on the production line informs the warehouse of the quantity required, and the rolls are transported to a designated area near the press, called the press supply area. In Figure 12, you can see the rolls in stock in the warehouse, as well as the rolls in stock in the area near the press.

Figure 12 - Raw material rolls in the raw material warehouse on the left. Raw material rolls in the press supply area on the right.

In addition to the foam, the pieces produced also require the application of velcro and a label. Regarding the labels, these are printed at the workstation in the quantity of the pieces that are packaged, which means, as they are needed. The velcros are stored in boxes at the bottom of the workstations and, when there is a PO, they are placed on the worktable to improve accessibility.

Press Cutting

Once the foam has been transported to the press supply area, the press operator can begin the process of placing the roll on the press so that everything is ready to begin production on the press. In addition, it is also necessary for the operator to place the appropriate cutter in the press to cut each reference geometry. The cutter is the steel plate that is inserted in the press, and each reference has a unique cutter, since it is this that ensures the cutting of the foam in the respective desired geometry. Figure 13 shows the foam roll already placed in the press and the shelf where the cutters are stored.

Figure 13 - Foam roll placed in the press in the left and centre. Shelf with the cutters on the right.

When these two stages are completed, the operator can start production on the press, which initiates the movement of the press belt, allowing the foam to be continuously transported to the cutting area of the press, where it is pressed and cut, according to the desired geometry. Afterwards, the conveyor also moves the cut pieces to the collecting area of the press, where the operator collects and puts them in their respective boxes to be stored, before being transported to the next process (remotion of the excess of material). Figure 14 shows the press in question and its collection area.

Figure 14 - Cutting press and collection area.

Drills Removal

Once the parts have been cut on the press, they are ready to move on to the next process. The cut pieces have an excess of material, called drills, which must be removed in order to comply with the specifications established by the customer. Figure 15 shows a comparison between a part before and after removing the drills.

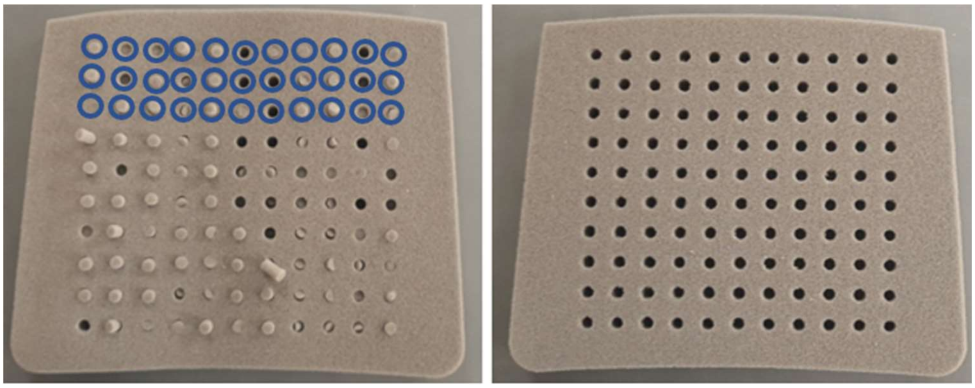

Figure 15 - Piece after press cutting with drills circled in blue on the left. Piece after having the drills removed on the right.

Application of Velcros and Label

Finally, once the pieces have been cut and the drills have been removed, we can proceed to the last process, which consists of applying the velcro and a label in the respective positions established. Each reference produced has specific positions defined for the application of the velcro and labels, which must be complied with, to fulfil what is expected by the customer. Figure 16 shows the positions where the velcro and labels must be applied on one of the references. The parts with the velcro and labels are packed in a box, to be stored in the finished product warehouse and then sent to the customer.

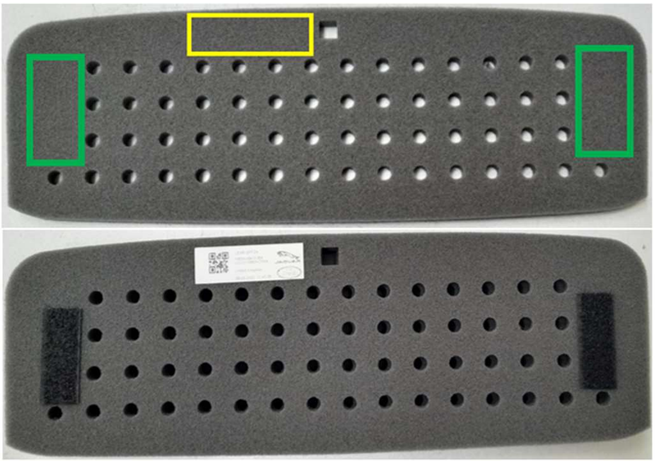

Figure 16 - Placement of the velcro ribbon and the label on a piece.

3.1.3 Layout of the Production Processes

In order to understand the material flow on production line 1, Figure 17 shows the layout of the plant, as well as the location of each workstation related to the various stages of the production process. In addition, the layout also indicates, through arrows, the path that the raw material takes from the starting point where it is in the warehouse, until the moment it reaches the state of finished product.

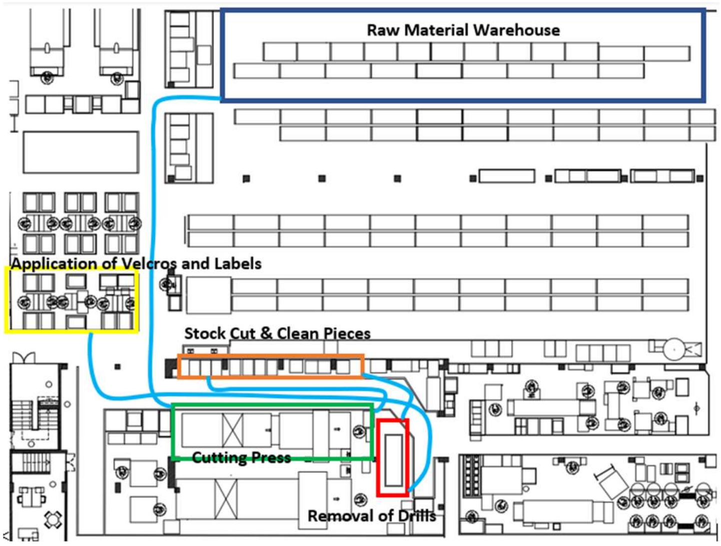

Figure 17 - Layout of production line 1.

From the analysis of the material flow, it is possible to conclude that there is a long distance separating the different workstations of the various production processes. This separation makes it necessary to transport a large quantity of semi-finished parts several metres by means of pallet trucks. This type of transport is a task without added value and indicates the need to improve the layout of the production line, since it negatively affects productivity and the lead time.

3.1.4 Identification of Problems and Opportunities for Improvement

The observation and monitoring of the various processes of production line 1 allowed a level of knowledge, which made possible to identify the existing problems. Throughout this chapter an analysis of the situation found initially will be made, identifying the main problems.

ABC Analysis and Takt Time Calculation

On this production line several different products are produced, as previously explained in chapter 3.1.1, and to understand which were the most important ones an ABC analysis was performed. In Table 3 you can see the quantities used in this analysis, which correspond to the expected demand for the period of one year. From this ABC analysis it was possible to construct a Pareto chart to be visually clear to perceive the results, as shown in Figure 18.

Table 3 - ABC Analysis of the products from production line 1.

ERT Reference	Annual Demand	% Total	% Cumulative	Class
C19032AD02B	251 486	17,5%	17,5%	A
C19032AB01B	251 211	17,4%	34,9%	A
C19032AA01B	250 553	17,4%	52,3%	A
C19032AC01B	250 509	17,4%	69,7%	A
C19032AF02D	132 307	9,2%	78,9%	B
C19032AE01D	131 413	9,1%	88,0%	B
C19032AH02B	43 366	3,0%	91,0%	C
C19032AI01B	42 281	2,9%	94,0%	C
C19032AJ01B	35 233	2,4%	96,4%	C
C19032AG01C	35 006	2,4%	98,8%	C
C19032AP01A	7 986	0,6%	99,4%	C
C19032AO01A	7 678	0,5%	99,9%	C
C19032AQ01A	1 134	0,1%	100,0%	C
Total	1 440 163	100%	100%	

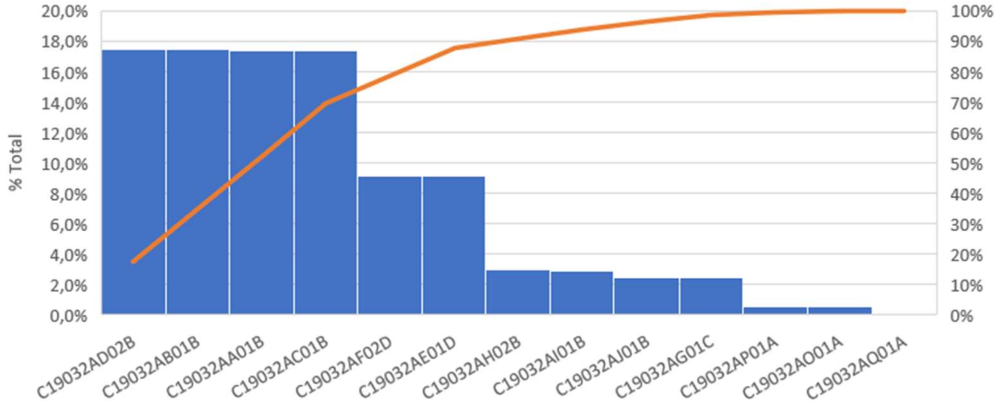

Figure 18 - Pareto chart of the products of production line 1.

From this analysis, six of the references, which correspond to class A and B products, account for about 88% of production, which means that they are the products to which more attention should be given.

Subsequently, an analysis of the takt time of the references produced was carried out in order to understand the pace that production would have to reach in order to ensure the capacity to produce at the same rate of the customer demand. For this calculation, it was necessary to know the total time available for production and the value of demand. All workstations on this production line work 5 days a week, with two shifts of 8.5 hours each. However, it is internally calculated that each shift only has 7.2 hours of effective production time, after removing the time for the maintenance and operators breaks. Furthermore, in relation to customer demand, a daily demand of 6128 pieces was calculated. Thus, the calculation of the takt time is shown in equation (3.1).

$$Takt\ Time = \frac{2*7.2*60*60}{6128} = 8.5\ s/part \tag{3.1}$$

The takt time calculation gave a value that needs to be reached in each process of the production line so that they are balanced, and deliveries are guaranteed on time to the customer. In this case, a part must be produced every 8.5 seconds at each process so that the production line has the capacity to produce at the same rate as the customer's demand.

Line Balancing

At the start of this project, it was necessary to record and analyse the time a product took in each of the stages of the production process, as this data was not available, but is essential to understand the state of the initial situation on the production line.

Therefore, the first weeks of the project were dedicated to the observation of the production processes and the measurement of the cycle times of each of the references produced, in order to have the data relative to all the products. This phase involved very close monitoring of the production processes and a close contact with all the operators, as they have the experience of the day-to-day work with all the products that are made.

After obtaining all this data, it was possible to calculate the average time that a piece takes to be produced in each production process. Using the estimated demand values for each of the references, and the respective times recorded in each production process, a weighting of the average time each piece takes in the various processes was calculated. On average, a piece takes 7.5 seconds to be cut on the press, 39.0 seconds to remove the drills and, finally, the application of velcros and labels takes 30.3 seconds. Calculating these values made it possible to create a Yamazumi graph, as shown in Figure 19. In this figure, the imbalance between the production processes is noticeable, where the process of drills removal is clearly the bottleneck of the production. Furthermore, it is also possible to observe a significant variability between the minimum, maximum and average time values of each process, which could be a sign of a lack of standardization. Therefore, the imbalance in the processes causes the appearance of waste and non-value-added activities throughout the manufacturing process, which is explained below.

Firstly, a large amount of WIP is generated between the cutting on the press and the removal of the drills. Figure 20 shows the amount of stock that accumulates on the shop floor. This excess inventory is one of the seven wastes identified by Taiichi Ohno and is indicative of another problem on the production line 1: the lack of a continuous piece-by-piece flow.

In addition, the imbalance of the production processes makes it necessary to pack all the pieces after the cutting press, which can be seen in Figure 21. This implies that in the following processes it is necessary to unpack, so that the work can be carried out. And, consequently, it is necessary to repackage again the pieces to move them between processes until they are ready to be send to the customer. This repetition of tasks without added value is a waste and is harmful to the productivity of this production line, since it causes an increase in lead time and, consequently, in the costs associated to the production line. Furthermore, this waste is indicative of the lack of a continuous one-piece flow, as in each process the operators are working by batches, on a single box at a time.

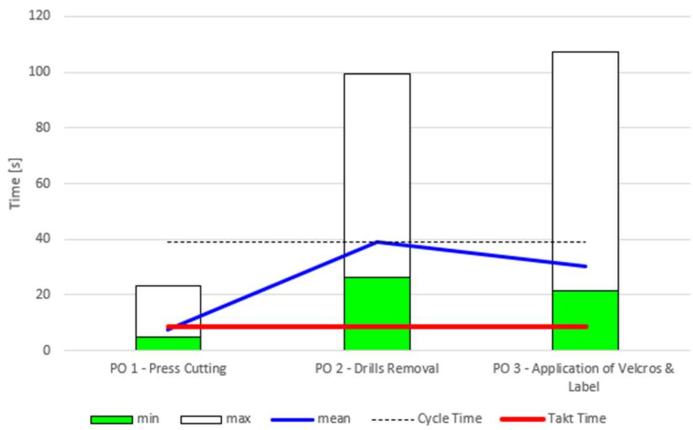

Figure 19 - Yamazumi chart of the initial situation on production line 1.

The Yamazumi chart used internally in the production plant and presented in Figure 19, doesn't indicate the time value of the multiple tasks of each operator. Instead, it shows the minimum, mean and maximum value of each production process, as the main objective of the production plant of using this chart is to reduce the variability between these three values. Therefore, the time of the different tasks done by each operator are analysed separately, in order to understand which of them are non-value-added activities.

Figure 20 - Excess of WIP between the cutting press and the drills removal.

Figure 21 - Packaging of the pieces after the cutting press.

Layout and Material Flow

In production line 1, each step of the production process is developed in a specific area of the shop floor, and what was found in the initial situation is that each workstation works as an isolated island, in a functional type of layout. This situation has several aspects that do not respect the Lean Manufacturing concepts and that, for this reason, should be changed to ensure a reduction in waste and an increase in productivity.

The initial layout doesn't ensure neither continuous flow nor one piece flow, since each workstation and each operator of the different production processes works isolated and separated by significant distances and produces large batches of products at a time. This situation causes the appearance of conveyance type waste, because each process produces large quantities of products, which need to be transported long distances, by means of pallet trucks, to the various production processes, along the production line 1.

Production Control on the Drills Removal

One of the problems found on the production line was in the process of removing the drills. In this process, there was no control over the number of pieces produced per shift or per hour. In fact, of all the production processes, this was the only one over which there wasn't any kind of control of its production.

The computer associated with the press is connected to the internal informatic system and so it is possible to analyse the quantity and type of reference that has been produced. In addition, in the process of applying velcro and labels, as it is the last process before dispatch to the customer, the operator registers in the informatic system the number and type of pieces that enter the finished product stock. This record allows the productivity of this production process to be consulted and analysed.

However, the process of removing the drills does not involve any record in the internal information system and, for this reason, it is not possible to register or consult the productivity or the quantity data, and the type of references produced. This is a situation that should be corrected, since the knowledge of what happens on the production line is essential for the introduction of new improvement measures.

3.2 Production Line 2

The second production line discussed in this paper is internally called "SE38X" and will be identified in this document as production line 2. This production line produces ten references for a client and these need to go through several processes to meet the client's specifications. In this project, the focus was only on the production processes of the wrapping area of production line 2. In chapters 3.2.1 and 3.2.2 we analyse the products that are produced and the processes that take place along that section of the production line.

3.2.1 Products Manufactured

The products of this production line are door handles for the interior of a car and, therefore, for each car one is needed for the left and one for the right door. A total of ten references are produced on this production line, and the only difference between them is the colour of the sewn thread and, for this reason, this difference is not of great relevance to the project in question. In Figure 22, is an example of a finished product of the production line 2. In Table 4, it can be seen the references produced in production line 2, as well as their estimated daily demand.

Figure 22 - Finished product of the production line 2.

Table 4 - References and estimated daily demand of products of the production line 2.

ERT Reference	Customer Demand per Day
S20025AA01A	1 500
S20025AB01A	1 500
S20025AA02B	10
S20025AB02B	10
S20025AA04B	10
S20025AB04B	10
S20025AA03A	93
S20025AB03A	93
S20025AA05A	25
S20025AB05A	25

3.2.2 Production Process

Regarding the wrapping area of production line 2, this process begins with the reception in the production line of the sewn nappa and plastic parts, as shown in Figure 23.

Figure 23 - Plastic part on the left. Sewn nappa pieces on the right.

The first process that takes place in the wrapping section is the removal of the excess material from the plastic part. This excess material is removed by using a tool that operates by compressed air, which is capable of simultaneously removing excess plastic from both a left and a right part, as seen in Figure 24.

Figure 24 - Tool for the removal of the excess material of the plastic parts.

After the plastic parts have the excess material removed, it is necessary to apply glue to both parts, since the final product is the bonding of these two components. The glue application is carried out using a compressed air gun and, therefore, it is necessary that the pieces are well secured so that they do not move with the force applied by the air pressure. For this reason, before the glue application, the plastic pieces are placed on a support, and the sewn nappa pieces are stapled to a sheet of cardboard, as shown in Figure 25.

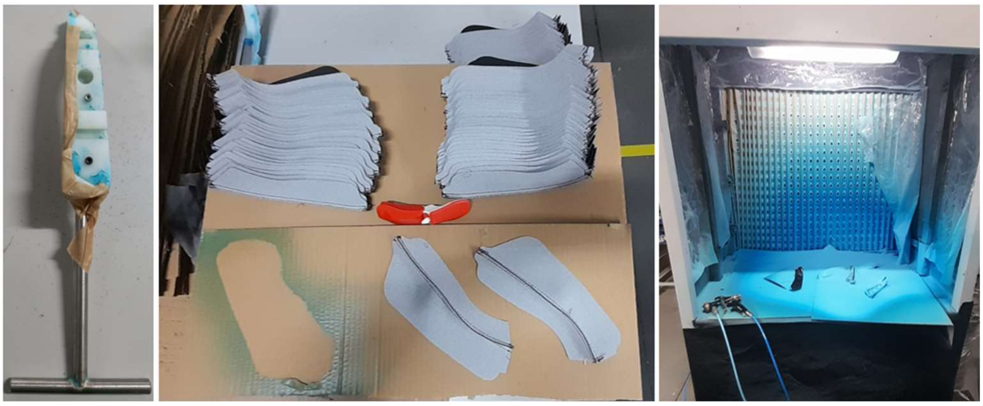

Figure 25 - Support for the plastic part on the left. Sewn nappa pieces stapled to the cardboard sheet on the centre. Glue workstation on the right.

Afterwards, with the glue already applied, the pieces are placed in an oven, so that the glue is activated. The oven has a conveyor inside that leads to the movement of the pieces, from the oven entrance, where the pieces are placed, to its exit, where the workstations of the next process are located. After the oven, the production line is divided into two sides, with one side working exclusively on the right-hand pieces, and the other on the left-hand pieces. However, the production processes and the operations to be carried out at the various workstations are the same.

At the exit of the oven, the plastic pieces are removed from the support and the sewn pieces are removed from the cardboard sheet. The plastic piece with the glue already activated is placed on another metal support, as shown in Figure 26, which allows the next process to be performed. This process consists of aligning the sewn piece with the plastic piece, through the groove marked in Figure 26.

Figure 26 - Metal support for the piece on the left. Piece placed in the support with a circle around the groove for the alignment on the right.

After the two pieces are already glued, they are ready to move on to the next process, which consists in creasing the sides and corners of the nappa piece on the plastic piece, in order to ensure that the entire piece is correctly glued and that no irregularities appear on the surface. During this process, excess material is also cut from the nappa piece, since it can difficult the creases on the edges of the plastic piece and, subsequently, cause defects to appear.

Once the two pieces have been joined, they need to go through two cycles in two different machines. Initially, they are inserted in the Pinach machine and, after performing a cycle in this machine, the pieces need to perform another cycle in the Vacuum machine. These two machines can be seen in Figure 27. The Pinach machine has capacity for four parts in each cycle, two left-handed parts and two right-handed parts. On the other hand, there are two vacuum machines, one for left-handed parts and one for right-handed parts. In addition, each vacuum machine has a capacity for four parts in each cycle, since there are four holders for the parts, as can be seen in the white circle on the right side of Figure 27.

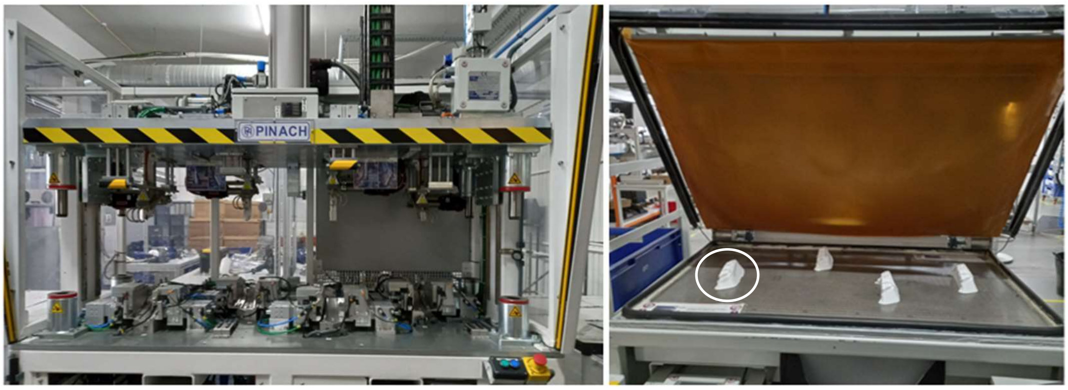

Figure 27 - Pinach machine on the left. Vacuum machine on the right, with the white supports for the pieces.

Finally, the parts leave the vacuum machines and enter the last process, which consists of sorting and packing the parts into boxes to be sent to the customer.

3.2.3 Production Line Layout

In Figure 28 we can see the layout of the wrapping section with the indication of all the workstations of the various production processes.

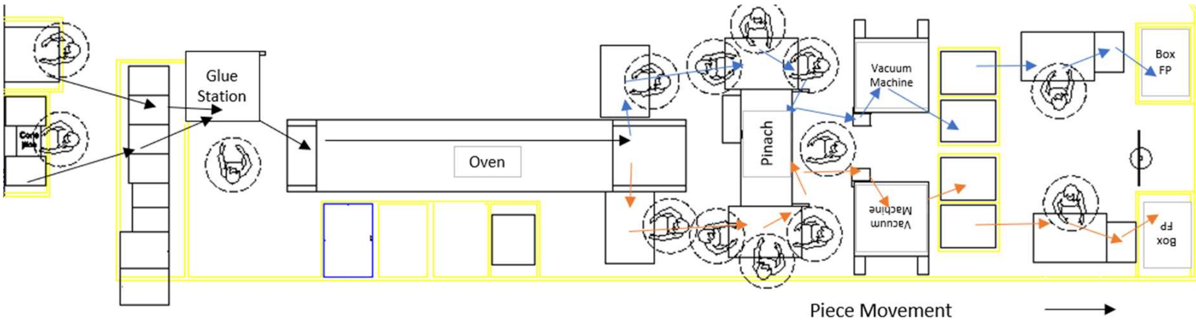

Figure 28 - Layout of production line 2.

By following the arrows of the material flow along the production line, can be concluded that there is an in-line flow. As already mentioned in the previous chapter, the production processes, after the oven, are split in two, with one side working on the right-hand door handles and the other on the left-hand ones. In Figure 28, the orange arrows indicate the right-hand side parts, and the blue arrows represent the left-hand side parts. Finally, the black arrows are processes that occur for both sides of the handles.

3.2.4 Identification of Problems and Opportunities for Improvement

Takt Time Calculation

Production line 2 suffered an increase in customer demand and as such, there was the need to recalculate the takt time value. Initially, this production line had to produce 11500 pieces per week, which translates into 5750 cars per week, since each customer car consumes 2 pieces.

So, there is a daily demand of 2300 parts per day, which means 1150 cars per day. This production line works in two shifts of 8.5 hours each, and has only 7.2 hours of effective production time, after removing the time for maintenance and the operators' break. Thus, the initial value of takt time, as calculated in equation (3.2), was 45.1 seconds per piece.

$$Initial\ Takt\ Time = \frac{2 * 7.2 * 60 * 60}{1150} = 45{,}1\ s/part \tag{3.2}$$

Subsequently, the demand value increased to 17000 pieces per week, which corresponds to 3400 pieces per day or 1700 cars per day. Thus, the takt time value was reduced to 30.5 seconds per piece, as seen in equation (3.3).

$$Actual\ Takt\ Time = \frac{2 * 7.2 * 60 * 60}{1700} = 30.5\ s/part \tag{3.3}$$

Line Balancing

At the beginning of this project, production line 2 was analysed to understand its functioning, as well as each task performed by the operators. Initially, there was a need for a total of 14 operators in each shift distributed by the various workstations, so that the number of parts produced reached the values established by the customer.

Furthermore, during this initial phase, the time taken by the pieces at each workstation on the production line was measured. The first operator, responsible for cutting the excess material from the plastic pieces and placing them on the support, took an average of 19 seconds for every two pieces. The second operator, responsible for stapling the nappa pieces to the cardboard, took an average of 25 seconds per 2 pieces. The third operator, responsible for the gluing station, took an average of 26 seconds per piece. Then, the two operators responsible for the alignment between the nappa pieces and the plastic piece took on average 28 seconds per piece. The two operators responsible for creasing the glued pieces took on average 28 seconds per piece. The next two operators took on average 25 seconds per piece. The last two operators before the cycle of the two automatic machines took an average of 25 seconds per piece. In addition, the automatic cycle of the Pinach machine takes 25 seconds per piece and the Vacuum machine takes 33.4 seconds per piece. One operator is responsible for both these machines. Finally, the last two operators responsible for the final control and packaging take 22 seconds per piece. The initial balancing of the production line can be seen in the Yamazumi chart presented in Figure 29.

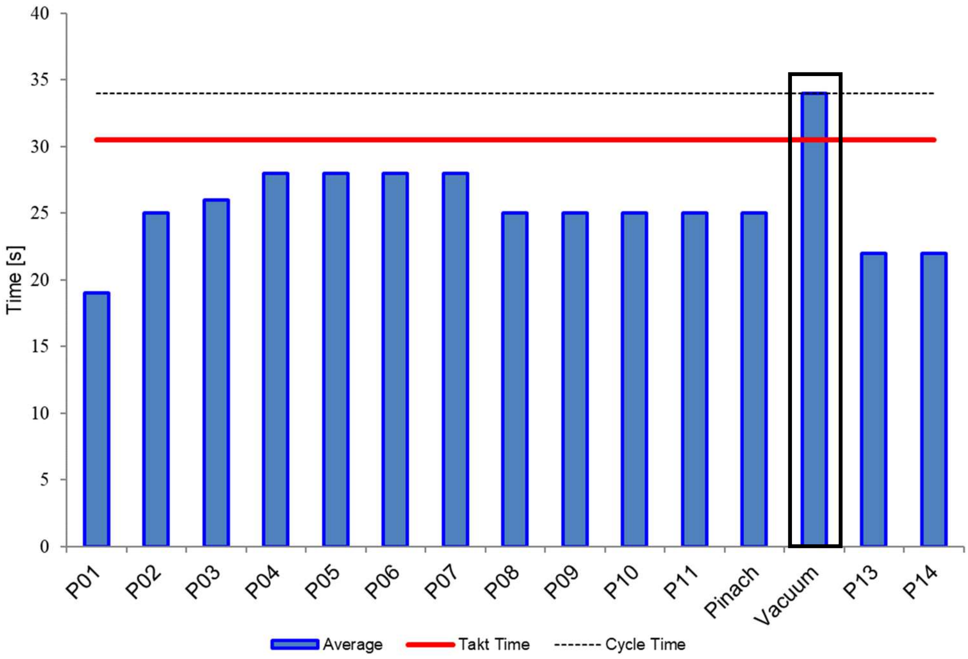

Figure 29 – Yamazumi chart showing the balancing of Production Line 2.

After analysing the production line balancing, is visible that the bottleneck is the workstation marked on the graph in Figure 29. These post concerns the vacuum machines that have a cycle time of 33.4 seconds per piece. This value is higher than the takt time and, for this reason, this is one of the workstations where it will be necessary to make changes to ensure production capacity without using the 3rd shift.

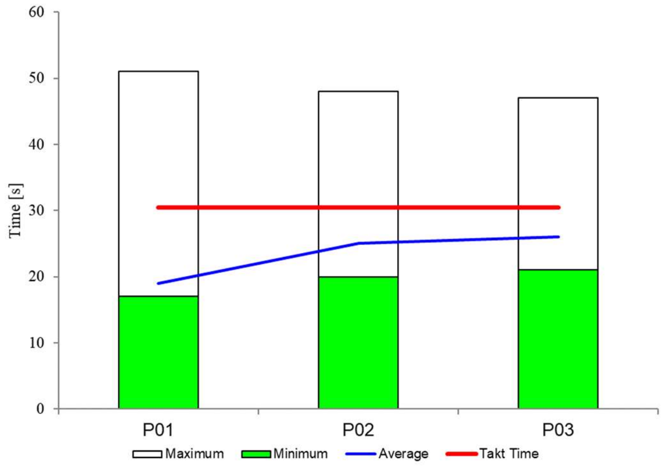

Figure 30 - Balancing of the production line 2.

Moreover, a great variability between the mean and maximum time values was also found in the workstations of the operators 1 and 2, as it is noted in Figure 30. This variability is due to the need of movement of the operators from their workstation to the exit point of the oven, where it is necessary to collect the supports for the plastic parts and the cardboards for the nappa pieces. From time to time, one of these two operators had to make an unnecessary movement to pick up the supports and the cardboards from the exit of the oven that is fifteen meters away, in order to carry on their work. In Figure 31, it can be seen with the dotted arrows the movement that the operators need to make. This type of movement is considered a motion waste as it is an activity that doesn't add value to the products.

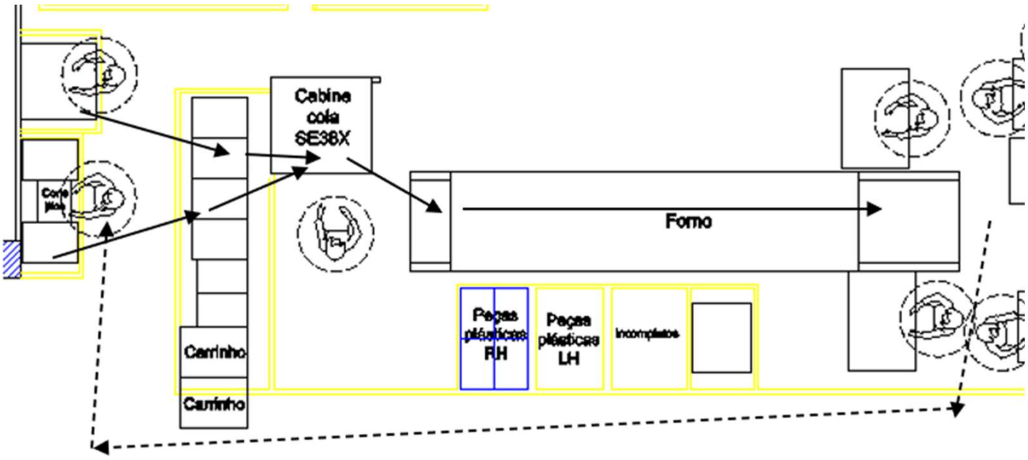

Figure 31 - Motion waste of the two operators in production line 2.

It should also be noted that the variability of the first two operators has a negative impact on the operator who performs the glue application of the pieces, in the glue booth, since sometimes he would run out of plastic pieces in the supports to apply glue, which, consequently, would cause stops along the entire production line. This waiting is also considered a waste in the production process and, therefore, there is the need to eliminate this waste.

Furthermore, the two workstations of the two initial operators are separate from the rest of the production line, which means that there isn't, neither a one-piece flow, nor a continuous flow along these processes. This layout causes an excessive movement from these two operators, which need to transport batches of pieces from their workstations to the glue application booth operator. In addition, the stapling of the nappa pieces to the cardboard sheets, has a cycle time much shorter than the rest of the production line, which generates an overproduction of pieces, which leads to a large amount of WIP between workstations. In Figure 32, it can be seen the excess WIP of stapled pieces.

Figure 32 - Excess of WIP between workstations.

4 Solutions Developed: Implementation and Analysis of Results

This chapter aims to explain the work and solutions developed throughout the project to address the problems identified in the initial situation and described in the previous chapter. Throughout this chapter, the work carried out on the two production lines will be discussed, as well as the comparisons between the before and the after of the implementation of the solutions, in order to understand the impact of each one of them.

4.1 Production Line 1

Firstly, we will look at the solutions implemented on production line 1 to address the problems detected in the initial phase of the project during the study of the initial situation.

4.1.1 KPI Implementation in the Drills Removal Process

One of the problems identified at an early stage of the project was the lack of production control in the process of removing the drills. Moreover, due to the lack of production control, the operators of this process did not have an established production objective to work towards. For this reason, one of the solutions implemented was the introduction of a Production Tracking Table, in which the operators write the number of pieces produced and the number of operators present during the various hours of the shift. The Production Tracing Table that was implemented in the drills' removal workstation in the production line 1 can be seen in Annex B.

The introduction of this Production Tracking Table made it possible to implement a KPI called Parts/Person/Hour (PPH), which calculates the number of parts that each operator produced for each hour of production. Thus, it is possible to have a much greater perception of the effective production capacity of this particular process, as well as to identify if there is any production failure.

4.1.2 Line Balancing

Number of Operators to Balance the Line

The first problem detected in the initial phase of the project was that the bottleneck of all production processes was the removal of drills, a process that was carried out manually. This operation required an average of 39 seconds for each part, which meant that it was way above the takt time and for that reason it was necessary to come up with a solution. There are two ways to reduce the time that the operation takes on average per piece, either by increasing the number of operators or by changing the process to reduce the cycle time.

In an initial phase, the solution chosen was to increase the number of operators responsible for this process. To do so, it was necessary to calculate the number of operators needed, in order to reach the takt time value. It is known that the work content of this production process is on average 39 seconds per piece, and that the takt time has a value of 8.5 seconds per piece, which results in a total of 4.6 operators to perform the operation of removing the drills per shift, as shown in equation (4.1). According to Dennis (2015), once the fraction of the number of operators is greater than 0.5, there is the need to add one more operator and, for this reason, 5 operators are needed for the drills' removal operation.

$$Number\ of\ Operators = \frac{39}{8.5} = 4.6\ operators/shift \tag{4.1}$$

Furthermore, despite not being the bottleneck of the production line, it was also necessary to perform the calculation of the number of operators for the velcro and label application process, because this operation had a cycle time higher than the takt time. For this process, the number of operators calculated was 3.6 operators, as seen in equation (4.2). Again, according to Dennis (2015), once the fraction of the number of operators is greater than 0.5 there is a need of 4 operators per shift to ensure a cycle time lower than the takt time.

$$Number\ of\ Operators = \frac{30.3}{8.5} = 3.6\ operators/shift \tag{4.2}$$

After having the necessary number of operators in each production process, a Yamazumi chart is obtained, where it is possible to observe that on average a part leaves each operation in a time lower than the takt time. The Yamazumi chart with the number of operators correctly distributed by the different production processes can be seen in Figure 34 and compared with the Yamazumi chart of the initial situation, that can be seen in Figure 33.

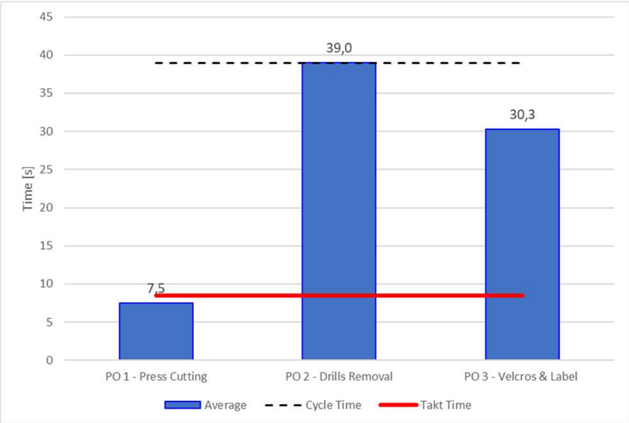

Figure 33 - Initial balance of the production line 1.

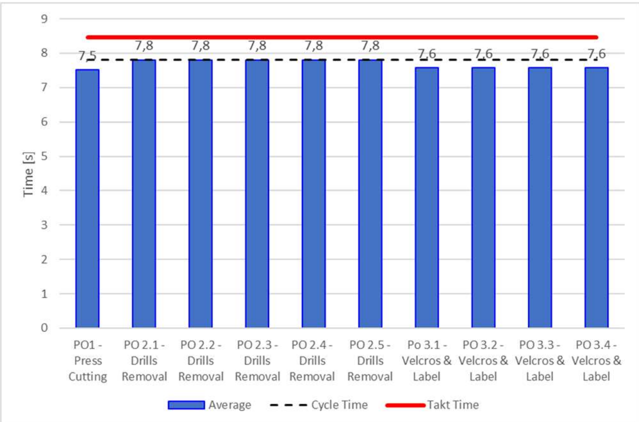

Figure 34 - Balance of the production line after calculating the correct number of operators.

After analysing the Yamazumi chart in Figure 34, it is possible to conclude that, with 5 operators in the drills' removal operation and 4 operators in the application of velcros and label, the time each piece takes in each operation is lower than the takt time, which means it is possible to produce at the pace of the customer's demand. With this calculated number of operators, a piece leaves the drills removal operation at every 7.8 seconds, and the velcro and label application operation at every 7.6 seconds, which is lower than the takt time of 8.5 seconds. At the same time, with this balance of the production line 1, it is possible to reduce substantially the excess of WIP that was detected in the initial situation, as each operation has a similar cycle time.

After calculating the number of operators needed for the initial situation, the following solution was to improve and reduce the cycle time of the drills' removal process, in order to be able to reduce the number of operators needed to reach the calculated takt time. The solution studied and implemented to change the process of removing the drills will be analysed in the following chapter.

Introduction of a Tool to the Drills Removal Process

Subsequently, the next objective was to reduce the number of operators needed in the drills' removal operation and, one way to do this is by reducing the cycle time of this process. One of the solutions that was studied, and then implemented, was the introduction of a mechanical tool that would allow the process of removing the drills to be altered, in order to reduce the time each piece takes during this process. The tool introduced is a metallic piece, shaped like the reference from which the drills are to be removed. As each reference produced has a unique shape and dimensions, a tool would be required for each one of them. However, given that there are six references that represent 88% of the demand, it was decided to only purchase this metallic tool for these products. An example of the tool can be seen in Figure 35.

Figure 35 - Tool acquired to remove drills.

Initially, the usage of this tool was very complex, with the operator having to place the part inside the mould, then manoeuvring the upper part of the tool to remove the drills, and, lastly, remove the part from the inside of the tool. Thus, after the implementation of this tool, the process of removing the drills began to take on average 21 seconds per piece, which allowed to recalculate the number of operators that would be necessary for this process. Taking into account this average time and the takt time value, it was calculated that 3 operators would be necessary to perform the removal of drills in a time lower than the takt time, as shown in equation (4.3).

$$Number\ of\ Operators = \frac{21}{8.5} = 2.5\ operators \tag{4.3}$$

However, it was found that this tool was too heavy to be used for a long period of time in this way by the operators, and that, sometimes, it also caused defects to appear on the pieces. For this reason, a new solution was developed for this tool, which consists of placing only the upper part of the tool on the workstation and insert the pieces in the position indicated for removing the drills, as it is shown in Figure 36.

Figure 36 - Upgraded method to use the tool for drills removal.

In fact, this new way of using the tool allowed the time for the removal of the drills to be even more reduced to an average of 16 seconds per piece, which in turn allows a reduction in the number of operators in this process to 2 operators, as seen in equation (4.4).

$$Number\ of\ Operators = \frac{16}{8.5} = 1.9\ operators \tag{4.4}$$

A comparison can be made of the times of the drills' removal throughout the various stages of the project. Firstly, the removal of the drills was done manually, which took an average of 39 seconds per piece. Then, the removal of the drills started to be carried out using the complete tool, which led to a reduction of the average time per piece to 21 seconds. And finally, the solution currently in use, which consists of using only the upper part of the tool, also led to a reduction in the average time per piece to 16 seconds. Figure 37 shows a comparison of the average time for the removal of the drills for a class A reference. This reference took 55 seconds initially, then, with the introduction of the complete metallic tool, it took 21 seconds, and, currently, takes an average of only 11 seconds per piece.

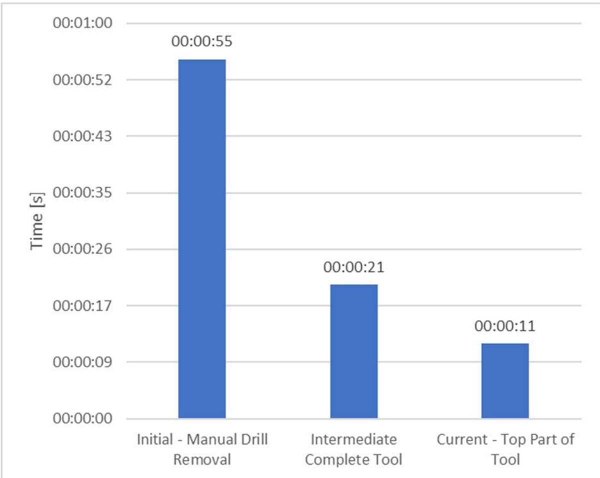

Figure 37 - Evolution of the average time for the removal of drills for a specific reference (C19032AB01B).

To sum up, Figure 39 shows the Yamazumi chart of the current situation in the production line, where 1 operator is responsible for the press cutting operation, 2 operators are in the drills removal operations and 4 operators are in the velcro and label application process. In the current situation, all the operations have a cycle time lower than the takt time, which is achieved with a lower number of operators, when comparing with the beginning of this project. For this reason, it can be concluded that there is an increase in the productivity of the production line, as it possible to produce the quantity demanded by the client, with a lower number of operators than in the initial situation. After the implementation of the mentioned solutions, the number of operators in the drills' removal process was reduced from 5 to 2 operators per shift, which translates in a reduction of 60% in the headcount. Furthermore, when analysing the production line 1, the reduction of operators in the removal of drills represents a 30% reduction in the headcount of the entire production line. Initially, there was the need for 10 operators in all the production processes, and, currently, there is only the need for 7 operators. Moreover, with the solutions that were implemented there was an increase of 39% in the Parts/Person/Hour KPI, which started at a value of 46 parts/person/hour and, in the end, reached the 64 parts/person/hour, as it is observed in Figure 38.

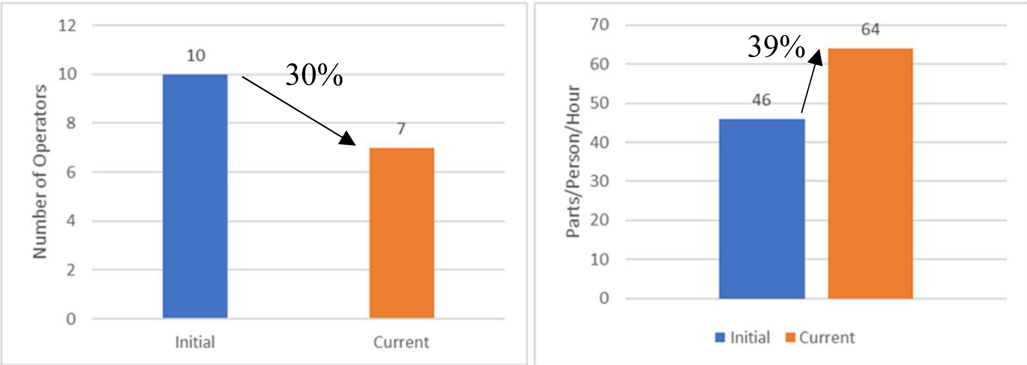

Figure 38 - Comparison in the number of operators and the parts/person/hour KPI between the initial and the current situation of the production line.

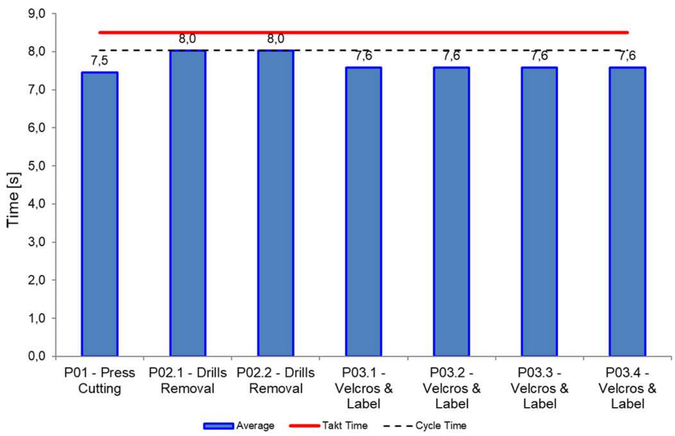

Figure 39 - Current balance of the production line after implementing the metallic tool.

Introduction of a Machine for the Drills Removal Process

Finally, the solution that was found to be the most economical and productive in the long term would be to purchase a machine that would carry out the removal of the drills automatically. This machine would reduce the time of the drill removal operation to approximately 7.9 seconds per piece, a value estimated by the machine supplier. Furthermore, this machine requires only one operator to ensure its correct operation, which further reduces the number of operators on the production line. Since the machine was not delivered in time, it was made an estimation of the results that could be achieved in the future, which will be analysed in the current chapter.

In this way, after the implementation of this machine there would be a reduction in the number of operators of 50%, in comparison with the current situation, where there is the need for 2 operators in the drills' removal process. Furthermore, the cycle time for removing the drills would be reduced from 16 seconds per piece, which was obtained with the introduction of the metallic tool in the process, to an average of 7.9 seconds per piece. Figure 40 shows the Yamazumi chart with the prediction of the balance of the production line 1 after the implementation of the machine for the drills' removal.

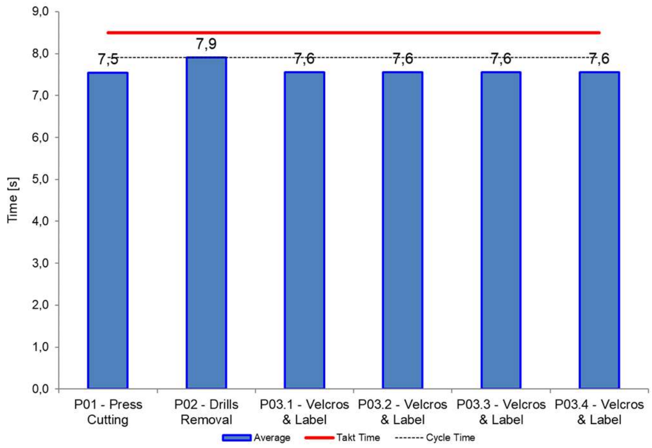

Figure 40 - Prediction of the balance of the production line after introducing the machine for the drills' removal.

To sum up, the purchase of this machine would reduce from 7 to 6 the number of operators needed in this production line, which, consequently, would increase the productivity. The increase in the parts/person/hour KPI would be of 18%, when comparing with the current situation. The predicted value of the PPH is of 76 parts/person/hour, which is 18% higher than the current value of 64 parts/person/hour, which was achieved with the introduction of the metallic tool, as it can be seen in Figure 41.

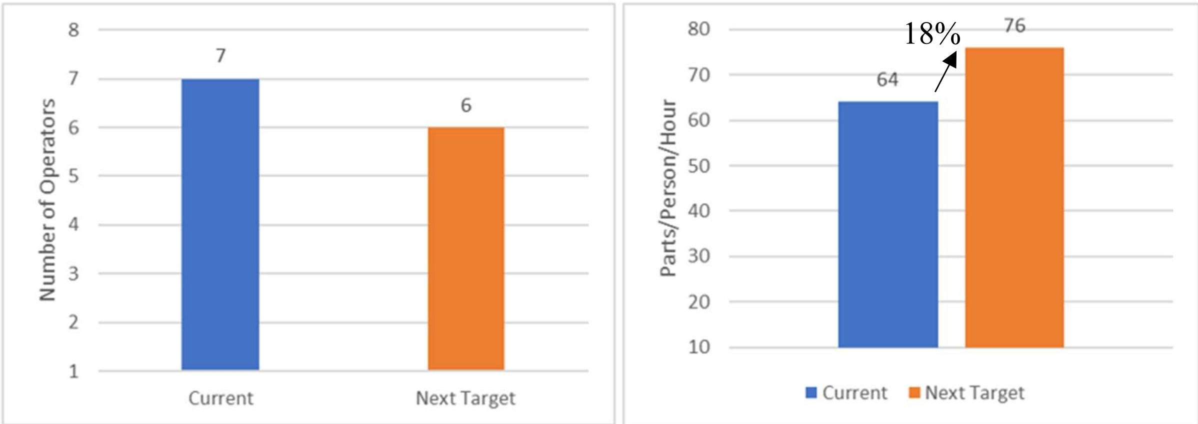

Figure 41 - Comparison of the number of operators and PPH KPI between the current situation and the prediction with the introduction of the machine for the drills removal.

4.1.3 Workstation Modifications

One of the solutions implemented was a change in the workplace of the operators from the drills' removal process. One of the problems detected was the production of a large amount of waste, due to the drills removed from the pieces. These drills ended up scattered all over the floor, resulting in a large amount of dirt, as it can be seen in Figure 42. Besides, the initial workplace of these operators was a small table, which was not ergonomic and did not have the right lighting conditions, as shown in Figure 42.

Figure 42 - Initial situation of the workplace of the drills' removal.

Figure 43 - Improved workstation with new table.

Thus, the two solutions implemented. One was to change the worktable for a larger one, as shown in Figure 43. This table also has lighting already installed, which substantially improves the working conditions of the operators. Besides, four holes were made in this table, which facilitates the cleaning of the drills that are removed from the pieces. This change allowed to reduce the number of drills scattered on the floor and, consequently, reduced the time spent by the operators in cleaning the workstation.

4.1.4 Change of Layout

One of the problems identified in the initial situation was the fact that the various production processes were too far apart from each other, which forced unnecessary and non-value-added transports between them. Besides, these non-value-added tasks caused an increase in lead time of the products produced in this production line, and, at the same time, it triggered a decrease in the productivity.

One of the solutions to reduce this waste would be to change the layout of the production line in order to reduce the number of transports and non-value-added operations. The new layout would reduce the distance between the process of removing the drills and the process of applying velcro and labels, which would substantially reduce the number of unnecessary operations and, consequently, would cause a reduction in the lead time. Furthermore, this change of the layout would also allow the introduction of one-piece flow in this production line, as the need to transport large batches for long distances would not be required anymore, and every operator could be focused on one piece at every moment. The proposed layout that would allow the reduction of a large number of tasks without added value can be seen in Figure 44, as well as the arrows that indicate the flow of the material. It should be noted that the change of layout was only studied after the solution of acquiring a machine for the removal of the drills came up. The implementation of this layout was not possible, because the delivering of the machine was longer than duration of the project.

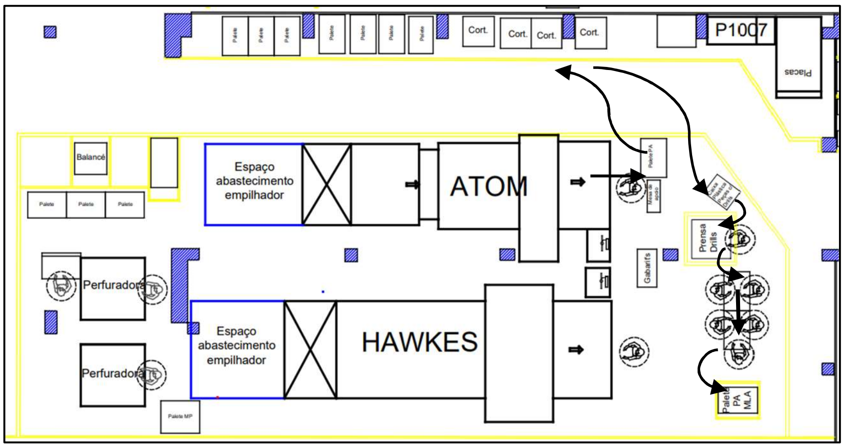

Figure 44 - Layout proposed to achieve one-piece flow and reduce transport and motion waste.

Initially, each piece presented an average lead time of 48 seconds, and of this time, 9.1 seconds were related to non-value-added activities, namely the packing and unpacking of the pieces in the different workstations of the production processes. By changing the layout, it would be possible to reduce the lead time to 43.5 seconds, reducing the non-value-added operations to 4.6 seconds per piece. This reduction is mostly due to the elimination of packing and unpacking operations throughout the production line. In fact, with these layout changes, it would only be necessary to do the packing of the pieces after the Velcro and label application, i.e. at the end of the production process. In summary, the layout change would allow a lead time reduction of 9%, as well as a reduction in non-value-added tasks of almost 50%, as it can be seen in Figure 45.

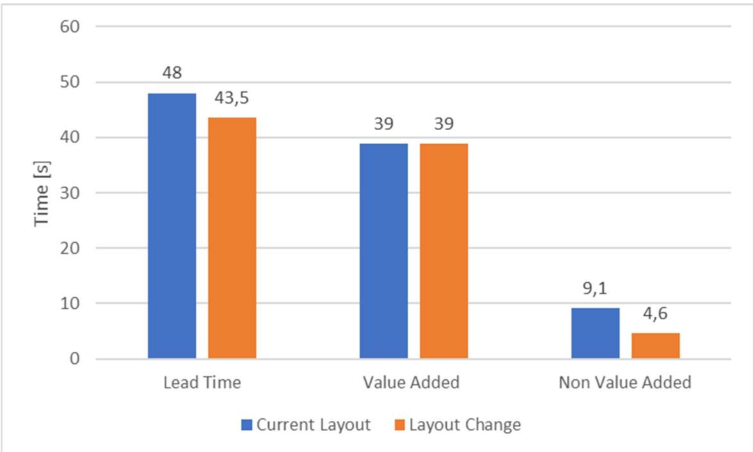

Figure 45 - Evolution of the lead time and tasks with and without added value due to the layout change.

Furthermore, associated to this new layout it was decided that there would be a separation of the tasks from the velcro and label application operations between different operators, which required the addition of one more operator, when comparing to the current situation. In fact, it was calculated that a total of three operators would be responsible for applying the velcros, one operator would be responsible for placing the labels and, finally, one operator would be responsible for packing the pieces into their respective boxes. This separation of the operations allows for an easier distribution of the tasks among the different operators, so that it is clear what each one is responsible for. For such, a new Yamazumi chart was made, which can be seen in Figure 46, which allows the distribution of operations among the various operators to be understood, after the alteration of the layout and the introduction of the machine for the drill removal.

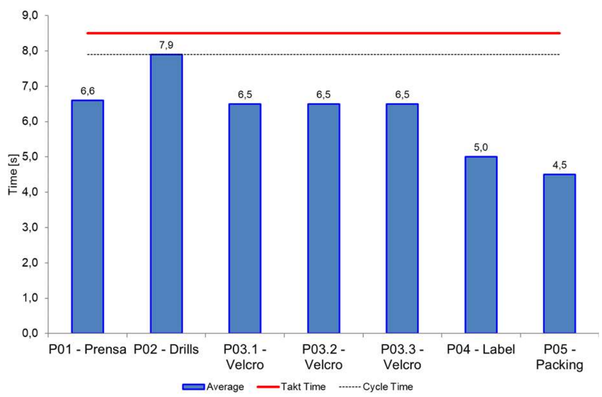

Figure 46 - Balancing of the production line after the layout change and the separation of the tasks between the operators.

After analysing the Yamazumi chart in Figure 46, it is possible to conclude that, with this balance in the production line, the last two operators will be pulling the pieces from the previous operators, as their cycle time is much lower in comparison with the previous operations. This situation is preferable, as it makes all the previous operators maintain a continuous flow, otherwise the production line will be stopped. Moreover, it is visible that, in the future, after the implementation of this solution, there will be the possibility to combine the tasks of the last two operators, in only one operator, as the time for these tasks is already close to the takt time.

4.2 Production Line 2

Secondly, we will look at the solutions implemented on production line 2 to address the problems detected during the initial situation study at the beginning of the project.

4.2.1 Capacity Increase in the Vacuum Machine

One of the problems identified initially was that the vacuum machines had a cycle time greater than the takt time and, for this reason, did not have the necessary production capacity to produce the number of parts required by the customer. Thus, to avoid opening a third shift, it was necessary to increase the capacity of these vacuum machines. The solution that was found and implemented was the purchase of more moulds, which allows the increase in the number of pieces produced per machine cycle. The purchase of four more supports, two for the vacuum machine that produce the pieces for the left side and two for the machine on the right side, allows the number of parts produced in each machine cycle to be increased to six, which means a reduction in the time per piece from 33.4 seconds to 22.3 seconds. In this way, it is possible to ensure the capability to produce the quantity required by the customer in the two shifts, avoiding the opening of the third shift, which would have a higher associated cost. Figure 47 shows one of the vacuum machines already working with the six moulds inside.

Figure 47 - Vacuum machine with the six moulds on the inside.

After the introduction of the moulds in the production line 2, there is an increase in the daily production capacity of 53%, which can be analysed in Figure 48. Initially, with four moulds in each vacuum machine, it was only possible to have a daily production capacity of 3000 pieces, with two shifts, whose value was lower than the customer demand of 3400 pieces, and, for this reason, it would require the use of a third shift. With the use of six moulds in each machine, there is a daily production capacity of 4600 pieces, which is higher than the customer demand, and means that there isn't the need to open the third shift.

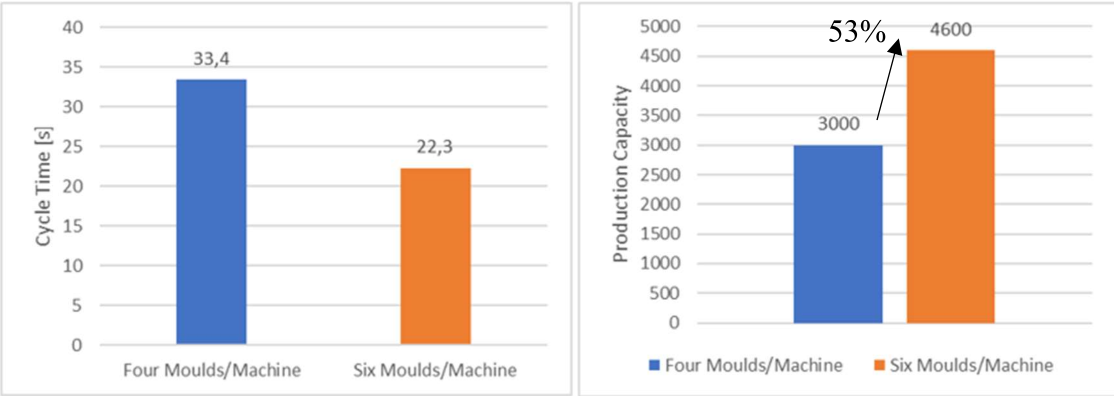

Figure 48 - Changes in the cycle time and the production capacity of the vacuum machines in the production line 2 after the introduction of two more moulds in each machine.

In addition, increasing the number of supports allows the cycle time of this operation in the vacuum machine to be reduced by approximately 33%, since there is a reduction in time per piece from 33.4 seconds to 22.3 seconds, which can be seen in Figure 48. The increase in the number of moulds also allowed the reduction of the number of pieces in WIP and the waiting time of these to start the cycle in the vacuum machine. In the initial situation, the vacuum machines had a longer cycle time than all the other previous processes, and for this reason, this is where the pieces accumulated and had to wait to start the cycle in the machines. In Figure 49, it can be observed, within the black rectangle, the new cycle time of the vacuum machines, with a value clearly lower than the calculated takt time. At the same time, in the same Yamazumi chart of Figure 49, it is possible to understand that all the workstations and operations are working below the takt time, which means that it is possible to produce in a rhythm of the customer demand.

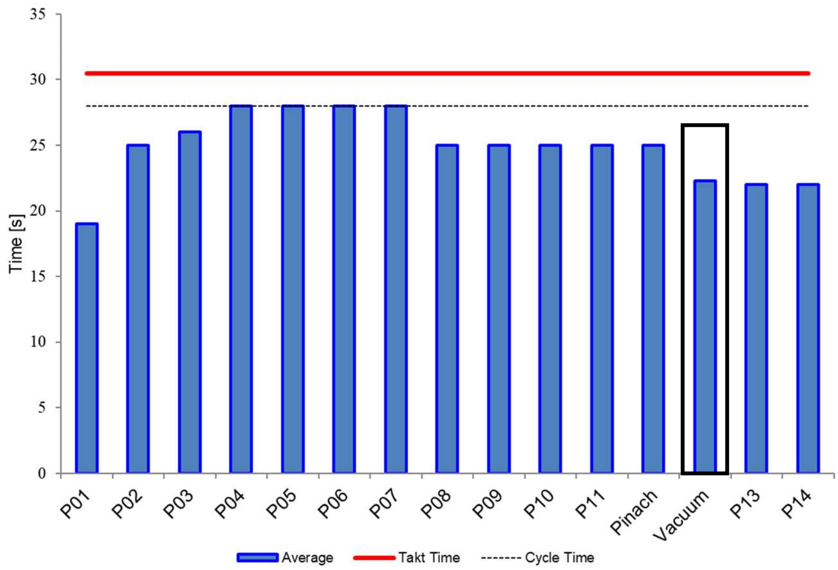

Figure 49 - Balancing of Production Line 2, after the introduction of two moulds in the two vacuum machines.

4.2.2 Implementation of a Rack

One of the problems that was identified initially was the need for transport and useless movements by the first two operators of the production line, to return the moulds and cardboards from the oven exit to the first two workstations.

The solution developed to solve this problem was the implementation of a rack with two paths, connecting the oven exit and the beginning of the production line, which can be seen in Figure 50. It should be noted that this rack was designed and built by the author. The calculated dimensions can be seen in Annex C. Moreover, the materials used were leftovers from other projects within ERT, which meant that they were already available. For this reason, this solution could be immediately implemented and did not require an initial investment.

This rack allows the transport by gravity of the supports and the cardboards from the exit of the oven to the two operators at the beginning of the production line, thus avoiding unnecessary movements of these. In addition, the second path of the rack allows the return of the plastic boxes to the exit of the oven, so that there is no need for any unnecessary movement by any of the operators present in the production line. Furthermore, this rack assures a constant flow of plastic supports, so that there are no interruptions in the work of the operator of the glue application station, as this was one of the problems observed in the initial situation.

Figure 50 - Rack implemented in the production line 2.

After analysing the production line, with the implemented rack it was possible to conclude that there was a reduction in the activities without added value, as the operators didn't have to move between their workstations and the exit of the oven. In the initial situation, this movement required covering 15 metres distance, which caused a high variability in the minimum and maximum values of the cycle times of the two initial operators. After the implementation of the rack, this variability was substantially reduced, which also made possible to reduce the inconsistency of the cycle time of the operator in the glue station. This reduction in variability can be observed in the adapted Yamazumi chart in Figure 51. In the initial situation, the maximum values of each operator were almost 50 seconds, which meant that it was almost the double of the takt time. This variability had consequences in all the production line, with unnecessary stoppages. However, after the introduction of the rack, the maximum values of each operator are of 35 seconds, which is much closer to the takt time. Having a lower variability is essential to maintain a continuous flow of parts in the production line, which is one of the principles of the Lean Principles.

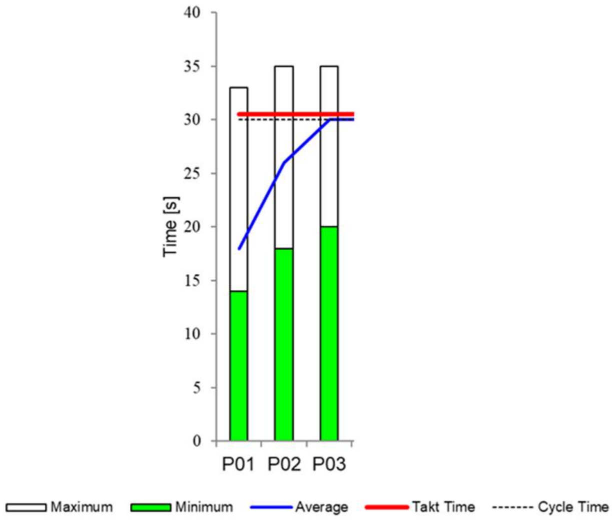

Figure 51 - Balancing of the first three operators in the production line, after the implementation of the rack.

Lastly, the implementation of the rack also facilitated the alteration of the layout of the first two operators, and their integration in the continuous one-piece flow of the production line 2, which will be explained in the following Chapter 4.2.3.

4.2.3 One-Piece Flow and Reduce Excess of WIP

Another situation identified in the initial situation was that the first 2 operators were not integrated in the one-piece flow of this production line, which meant that they worked isolated. At the same time, the operator produced a lot of WIP of stappled pieces and had to make some unnecessary movements due to its separation from the production.

One of the implemented solutions was the integration of these 2 operators in the production line, to guarantee a continuous one-piece flow, and, for this reason, avoiding the presence of excess of WIP and unnecessary movements. With this solution, all the operators are working closely and focused on a single piece at every single moment, which follow the principles of the Lean Manufacturing. This solution required a change on the layout of the production line, which can be observed in Figure 52, where there is a comparison with the initial layout of the production line.

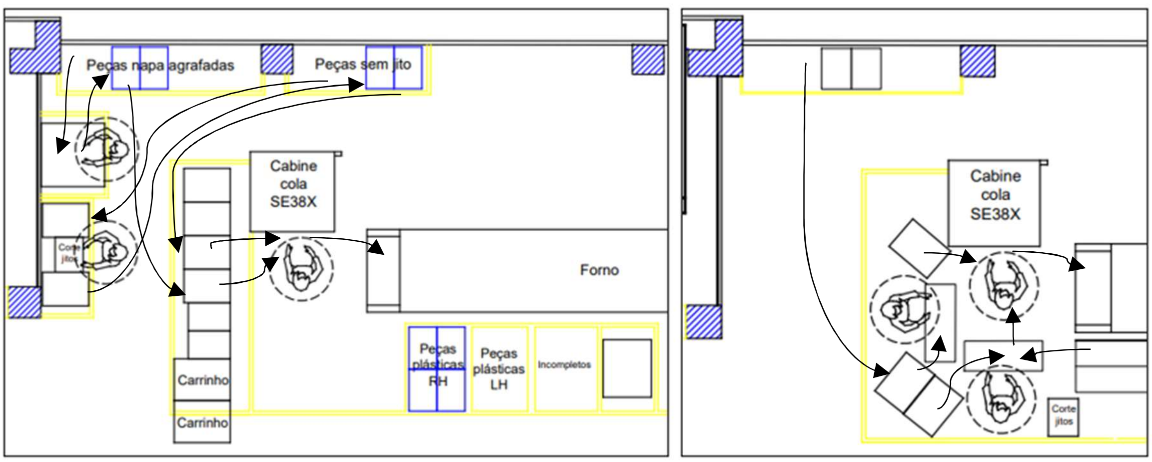

Figure 52 - Comparison of the layout and the Spaghetti Diagram between the initial (on the left) and current situation (on the right).

The integration of the 2 operators in the production line made it possible to eliminate three types of waste that were identified in the initial situation. The first waste eliminated was the overproduction of pieces, which generated a lot of WIP, that occupied a lot of space in the production plant. In addition, transport and motion waste were also eliminated, as the operators were integrated in the production line, they do not need to move to pick-up pieces and transport them. In Figure 52, it is also possible to see the difference in the Spaghetti Diagrams made before and after this layout revision.

Finally, the layout change means that there is a smaller area being used in this production line, which enables the cleared area to be used for other operations, in case it is needed. Furthermore, a continuous one-piece flow was achieved on the entire production line, which was one of the initial objectives of this project.

4.2.4 Process Alteration

One of the solutions that was implemented was the alteration of the process of stappling the nappa pieces to the cardboards. This operation was totally non-value added, as it was an excess-processing activity that wasn't required by the customer, as the only activity necessary is the application of glue to the pieces. For this reason, a system to replace the stappling of the pieces to the cardboard was introduced, which can be seen in Figure 53. It consisted of a vacuum system that holds the nappa pieces in the glue workstation, so that the operator could apply the glue.

This system reduces the cost of the operation by avoiding the use of the cardboards and, consequently, the time of stappling the pieces. In fact, in the initial situation, the operator responsible for stapling the nappa pieces to the cardboard took an average of 25 seconds. With this solution, the operator only had to put the pieces in their correct position, which significantly reduced the cycle time of this operation. This reduction opened the possibility of reducing to one operator before the glue station.

Figure 53 - Change of the process of stapling the nappa pieces to the cardboard.

This solution allowed to reduce in 7% the number of operators per shift in the production line 2, from 14 operators to 13 operators, which has an increase in productivity, as it can be seen in Figure 54. Moreover, there would be an increase in the parts/person/hour KPI from 18.4 to 19.1 parts/person/hour, which represents an increase of 4%, which can be analysed in the Figure 54.

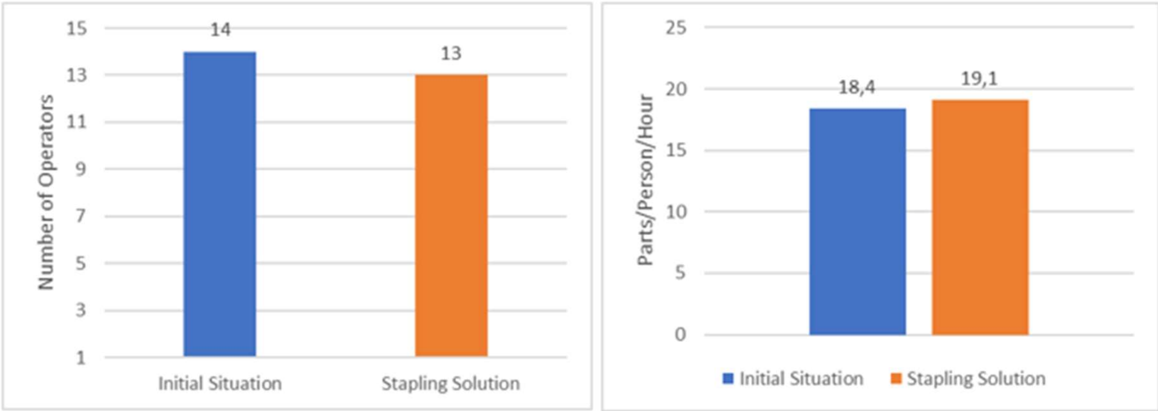

Figure 54 - Evolution of the Parts/Person/Hour KPI with the reduction of one operator in the production line 2.

Lastly, with the implementation of this solution, there was no need to use the cardboard, which represented a cost in the initial situation. The elimination of this component will allow an annual saving of 4400 euros.

4.2.5 Layout Change and Line Balancing

Lastly, a solution that was implemented was another change of layout, to make the operators workstations in a line. At the same time, it was introduced a rebalance of the operations in the alignment and creasing operators, which are marked in black in Figure 55. These operators are also responsible for the cut of the excess of material. In the initial situation, the operations were already well distributed, with none of them with a cycle time over the takt time. However, all the operators had to cut the excess of material, which doesn't add value to the finished product. For this reason, there was a redistribution of the operations between these operators, in order to make the cut of the excess of material only necessary in the last operator of each side of the production line, which are circled in red in Figure 55.

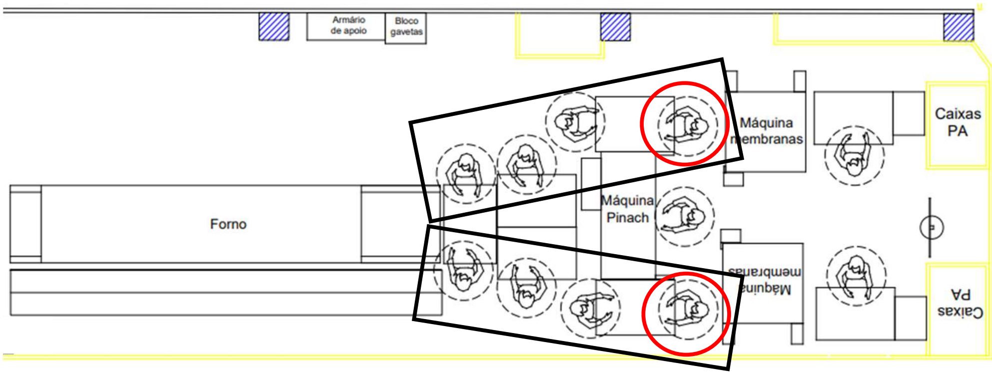

Figure 55 - New layout of the production line 2.

Moreover, in the future, a solution to be implemented would be to the change the geometry of the nappa pieces, which would eliminate the need to cut the excess of material. This new geometry would allow to reduce the number of operators by 2 in each shift, as the operation of the 2 operators circled in red in Figure 55 wouldn't be needed. Therefore, there would be a reduction in the lead time of the pieces, with the elimination of one operation, and an increase in the productivity. In fact, the predicted increase in the parts/person/hour KPI is estimated to be from 18.4 to 21.4 parts/person/hour, when comparing with the initial situation of 14 operators per shift, which represents an increase of 16%, which can be seen in Figure 56.

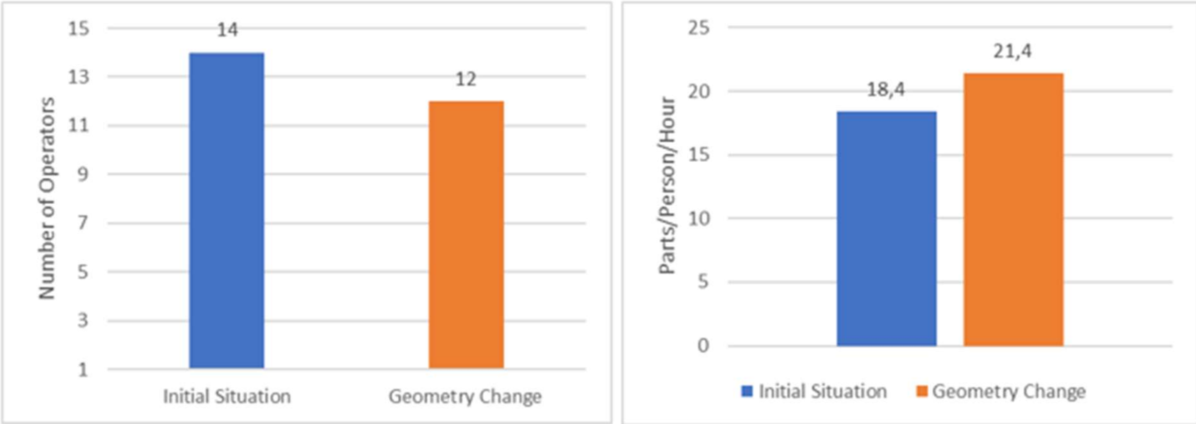

Figure 56 - Expected increase in the Parts/Person/Hour KPI with the reduction of the number of operators in the production line 2, after the geometry change.

To sum up, the change of geometry wasn't implemented during this project. However, it was done a test, to understand if the new geometry of the nappa piece would eliminate the need to cut the excess of material. With this test, it was possible to conclude that, after the alignment and creasing operations, there wasn't any material in excess. For this reason, the last operators before the Pinach machine can be freed to other production lines in ERT production unit.

5 Conclusions and Perspectives for Future Work

This project was established with the objective of increasing the productivity in two production lines, by the reduction of activities without added value, so that all the resources were used in the best way possible. In a progressively competitive market, companies need to adopt strategies, where the focus is the increase in productivity and the reduction of costs, through the elimination of all the operations the customers aren't willing to pay for. The application of these strategies requires a continuous search of opportunities for improvements.

The project required the study and understanding of Lean Tools. These tools were crucial as they were the theoretical base for the improvement solutions implemented in both the production lines. The concepts of one-piece flow and continuous flow were one of the most important studied, as they are one of the targets that Lean Manufacturing intends to achieve. Furthermore, the types of Muda, or waste, that can be found in production processes, were also studied to allow their identification throughout the project. Finally, the ideal type of layout and line balancing were also essential tools to identify improvement opportunities in the production lines focus of the interventions.

The solutions founded produced immediate results in the two productions lines. The results obtained represent significant improvements for ERT, as they increased the productivity, mainly through the reduction of the cycle times in several operations and, consequently, reducing the number of operators needed.

In production line 1, that was in implementation phase, there was a reduction in the number of operators and in the lead time of the pieces, in comparison with the initial situation. Since the integration in the productivity increase project, there was the need to collect as much data as possible, to keep records and to compare the evolution of the cycle times of the different production processes, as well as to calculate the number of operators required to produce at the pace of the customer demand. The continuous update of the data is essential to be able to fully analyse and compare the improvements made after the implemented changes. In fact, there was a decrease in 30% in the number of operators needed, with a reduction from 10 to 7 operators, between the initial and the current situation of the production line. This reduction was obtained with changes in the drills' removal process, which was the initial bottleneck of the production line. Furthermore, it was also estimated that the introduction of a machine to execute this operation, would further reduce from 7 to 6 the number of operators. In terms of productivity, this parameter was evaluated with the introduction of the Parts/Person/Hour KPI, which was the value in which ERT was interested. When comparing the Parts/Person/Hour between the initial situation and the current situation, it was possible to conclude that there was an increase of 39% in this value, from 46 to 64 parts/person/hour. Moreover, with the introduction of the machine for the drills' removal, it was expected a further increase of 18%, from 64 to 76 parts/person/hour. Lastly, the layout changes that were studied and could be implemented, would have a reduction in the lead time of the pieces in the production processes. This reduction is due to the decrease in 50% of the time of the tasks without added value, such as the packing and unpacking of the pieces in all the production processes.

In production line 2, the improvements were mainly focused on the reduction of tasks without added value, but also in increasing the production capacity according to customer demand. Firstly, there was the addition of two moulds in each of the vacuum machines to increase the capacity of the production line. In the initial situation, the production capacity of these machines was at 3000 pieces per day, which was lower than the customer demand. So, the increase in the number of moulds was fundamental to the satisfaction of the customer. Moreover, the next improvement was the introduction of a rack to avoid the excessive movement of the operators, which doesn't add value to the products. This change allowed the reduction of the variability of the cycle times of the first two operators, which is necessary to maintain a continuous flow of pieces in the production line. Furthermore, the rack also facilitated the layout's change, to eliminate the excess of WIP, which resulted from the lack of one-piece flow and the separation of these first two operators from the rest of the production line. The integration of these operators allowed a continuous one-piece flow, with an in-line layout, which is one of the preferable for a production line. Furthermore, with the change of the process of stappling the nappa pieces to the cardboard, it was possible to reduce the number of operators per shift. With this change, the number of operators needed would be reduced from 14 to 13 per shift, which would, consequently, increase the productivity of this production line. In fact, the productivity was also measured with the Parts/Person/Hour KPI, where there was an increase from 18.4 to 19.1 parts/person/hour. Lastly, with the redistribution of the operations between the alignment and creasing operators, and the change of the geometry of the nappa pieces, it would be possible to further reduce the number of operators. In fact, it was calculated it would be possible to reduce by 2 the number of operators in each shift, which would increase the Parts/Person/Hour KPI to 21.4, in comparison with the initial situation.

In terms of costs, the reduction in the number of operators allows the reduction of the annual costs associated to each production line. In the production line 1, the reduction of 3 operators, when comparing with the initial situation, lets an annual saving of approximately 45000 euros. For the production line 2, the current reduction of 1 operator makes for an annual saving of 15000 euros. In addition, the elimination of the use of cardboards allows a further annual saving of 4400 euros in the production line 2. Therefore, the total of the two production lines grants a total annual saving of 64400 euros. Furthermore, the implementation of the other studied solutions in the future will produce an even greater annual savings.

To sum up, the project was successful, because the main objectives for both the production lines were achieved. However, there was a limitation throughout the work as the length of the project wasn't enough to implement all the improvement opportunities identified. The changes take time and resources, so to implement all the solutions it would be necessary more than 18 weeks. However, it was still possible to observe the clear improvement present in the production lines. And, moreover, predictions were made with the results expected to achieve, when all the opportunities mentioned are put into effect.

In terms of future works, there is an opportunity to implement more digitalised and automated KPIs, in comparison with the Parts/Person/Hour. As this KPI was already implemented in other production lines in ERT, to maintain the consistency and be possible to compare results, it was decided that the best option was to maintain this KPI in all the production lines. However, there is also a chance to start a digitalisation process in the collection and presentation of the KPIs. At the same time, there is the possibility to introduce a more complex KPI, that could register and transmit new detailed data, in order to fully understand the problems, present in the production lines. For example, the implementation of the OEE KPIs, would allow the monitoring of the availability, performance, and quality of the machines, to identify more opportunities for improvements, such as setup monitoring, corrective and preventive maintenance and quality performance. Furthermore, there is also the possibility to implement solutions to reduce the setup operations of the machines, which weren't the focus of the project analysed in this dissertation. The introduction of standardized work in the setup operations, could reduce their time and, consequently, increase the productivity of the production lines.

Finally, the continuous identification of opportunities for improvements is a cyclical process without an end, in the incessant search to achieve perfection. For this reason, it is needed to continue and, preferably, expand this project to more production lines, to ensure a continuous growth in the productivity of the production processes, in a progressively more competitive market.

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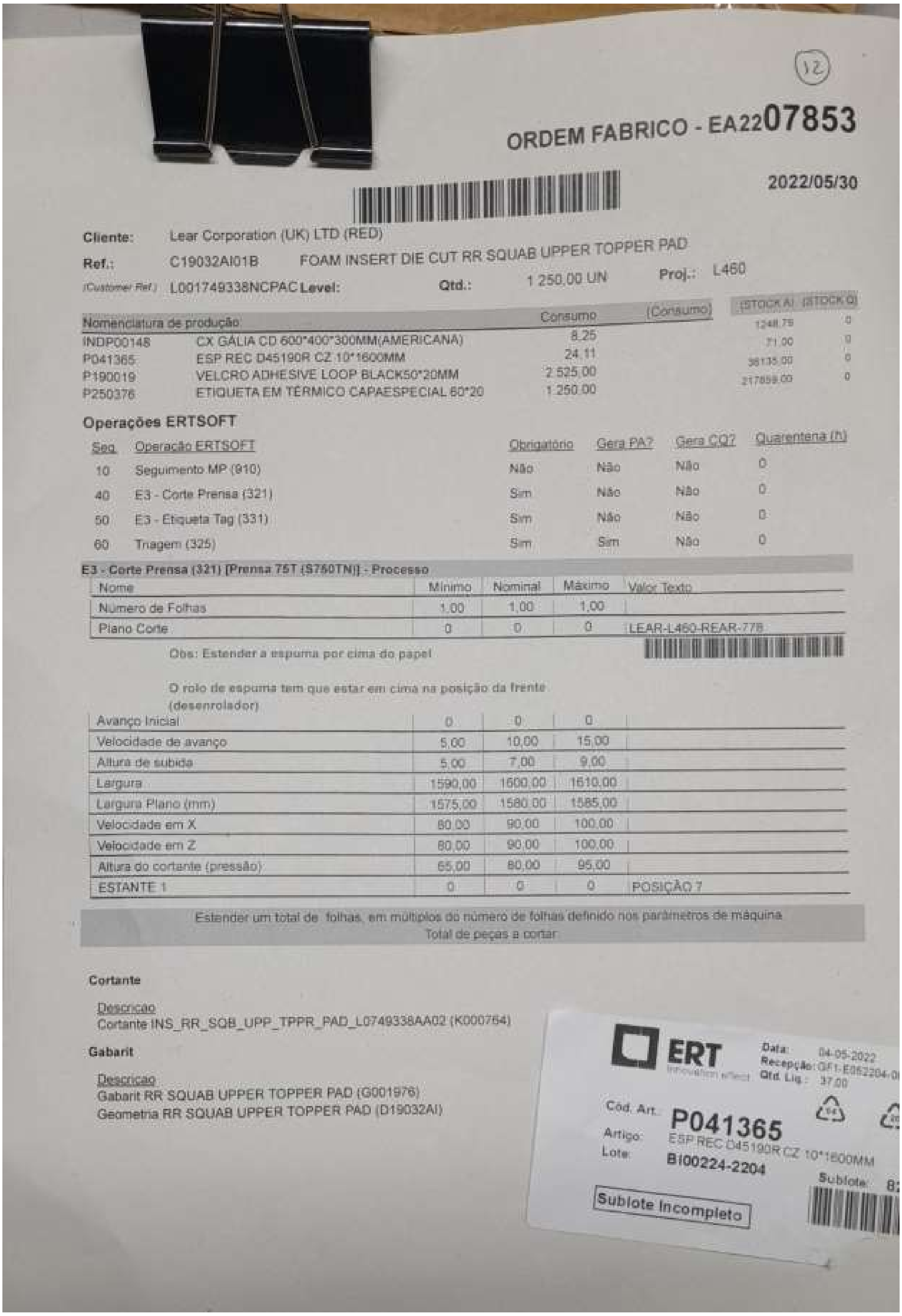
ANNEX A: Example of a Production Order



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ORDEM FABRICO - EA2207853

2022/05/30

Cliente: Lear Corporation (UK) LTD (RED)
Ref.: C19032AI01B FOAM INSERT DIE CUT RR SQUAB UPPER TOPPER PAD
(Customer Ref.) L001749338NCPAC Level: Qtd.: 1 250,00 UN Proj.: L460

Nomenclatura de produção		Consumo	(Consumo)	(STOCK A)	(STOCK Q)
INDP00148	CX GÁLIA CD 600*400*300MM(AMERICANA)	8,25		1248,75	0
P041365	ESP REC D45190R CZ 10*1600MM	24,11		71,00	0
P190019	VELCRO ADHESIVE LOOP BLACK50*20MM	2 525,00		36135,00	0
P250376	ETIQUETA EM TÉRMICO CAPAESPECIAL 60*20	1 250,00		217859,00	0

Operações ERTSOFT

Seq.	Operação ERTSOFT	Obrigatório	Gera PA?	Gera CQ?	Quarentena (h)
10	Seguimento MP (910)	Não	Não	Não	0
40	E3 - Corte Prensa (321)	Sim	Não	Não	0
50	E3 - Etiqueta Tag (331)	Sim	Não	Não	0
60	Triagem (325)	Sim	Sim	Não	0

E3 - Corte Prensa (321) [Prensa 75T (S750TN)] - Processo

Nome	Mínimo	Nominal	Máximo	Valor Texto
Número de Folhas	1,00	1,00	1,00	
Plano Corte	0	0	0	LEAR-L460-REAR-778

Obs: Estender a espuma por cima do papel

O rolo de espuma tem que estar em cima na posição da frente (desenrolador)

Avanço Inicial	0	0	0	
Velocidade de avanço	5,00	10,00	15,00	
Altura de subida	5,00	7,00	9,00	
Largura	1590,00	1600,00	1610,00	
Largura Plano (mm)	1575,00	1580,00	1585,00	
Velocidade em X	80,00	90,00	100,00	
Velocidade em Z	80,00	90,00	100,00	
Altura do cortante (pressão)	65,00	80,00	95,00	
ESTANTE 1	0	0	0	POSIÇÃO 7

Estender um total de folhas, em múltiplos do número de folhas definido nos parâmetros de máquina
Total de peças a cortar

Cortante

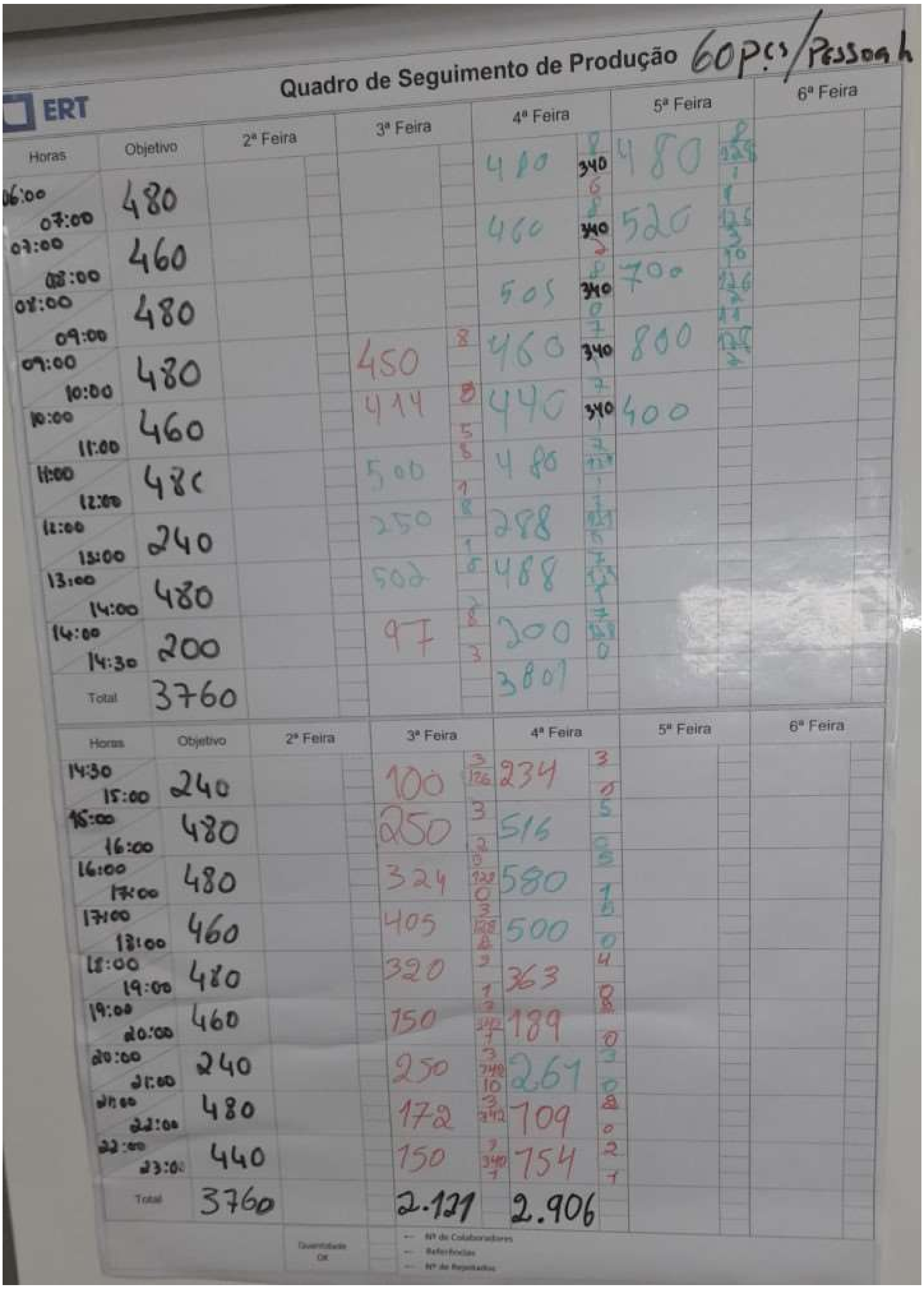
Descricao
Cortante INS_RR_SQB_UPP_TPPR_PAD_L0749338AA02 (K000764)

Gabarit

Descricao
Gabarit RR SQUAB UPPER TOPPER PAD (G001976)
Geometria RR SQUAB UPPER TOPPER PAD (D19032AI)

ERT innovation effect
Data: 04-05-2022
Recepção: GF1-E052204-0
Qtd. Lig.: 37,00
Cód. Art. P041365
Artigo: ESP REC D45190R CZ 10*1600MM
Lote: BI00224-2204
Sublote: 8
Sublote Incompleto

ANNEX B: Production Tracking Table



ANNEX C: Rack Dimensions

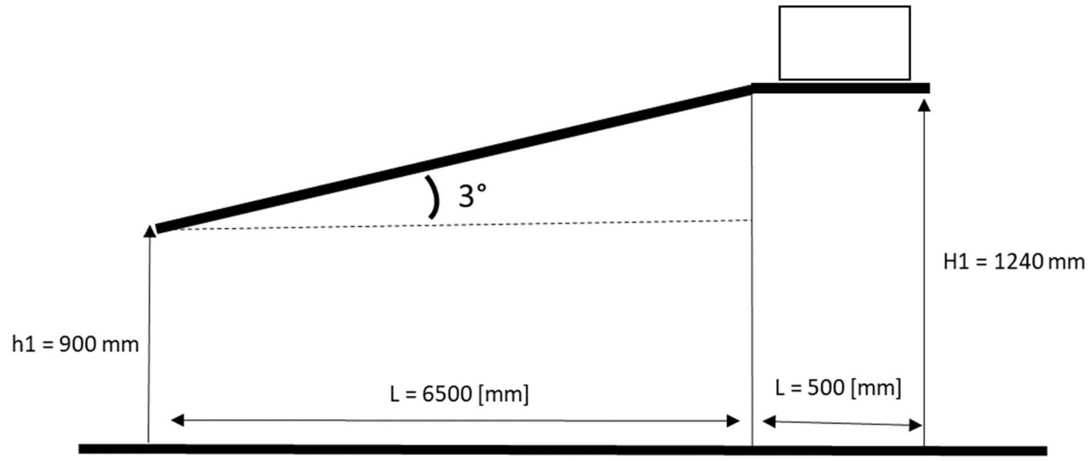


Figure 1 – Dimensions for the rack of the plastic supports.

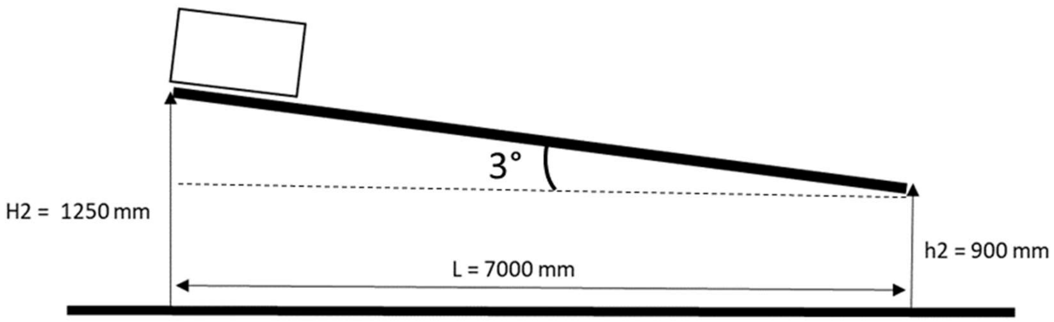


Figure 2 – Dimensions for the rack to return the boxes.