

FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Application of the "LEAN Automation" methodology to the production process of a seafood industry

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Automation Branch**

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Resumo

A presente dissertação centra-se na aplicação dos princípios do Lean manufacturing para resolver dois desafios operacionais em duas linhas de produção de uma empresa industrial de pescado.

Numa fase inicial, procedeu-se a uma análise aprofundada e a uma modelação dos processos em computador, tendo sido identificados "gargalos" na produção, tempos de espera excessivos e um elevado dessincronismo entre os processos da linha e as máquinas presentes. Foram desenvolvidos gráficos que ilustram o funcionamento da linha para permitir analisar o funcionamento da mesma e o código do respetivo controlador. Posteriormente, as soluções foram implementadas nestes esquemas e passou-se para a fase prática de resolução dos problemas na linha.

Para resolver estes problemas, foram implementados os princípios e ferramentas do Lean manufacturing baseados na pesquisa realizada, como o Kaizen, o "Standardised work" e o Line balancing, para otimizar o tempo de ciclo da linha de produção, reduzindo os tempos de espera e tornando o fluxo do sistema muito melhor e mais suave.

Os resultados da implementação Lean demonstrou uma melhoria significativa na produção de 33,4% e uma redução no custo de produção por kg de produto de 10,77% no produto 1 e um aumento considerável de 33,2% na produção e um custo de produção reduzido de 5,26% no produto 2. Os objetivos pretendidos pela empresa foram alcançados com sucesso, sem quaisquer custos nas soluções implementadas.

O segundo projeto desta dissertação tem como objetivo desenvolver um sistema de monitoramento de produção para uma linha de produção de filetagem de bacalhau para ser possível aceder remotamente e em tempo real.

Através da aplicação de um PLC com servidor web integrado, foi desenvolvido um programa que fornece informações em tempo real sobre o funcionamento da máquina de filetagem de bacalhau, a produção total da linha, a taxa de produção por minuto, o estado de funcionamento da máquina e o tempo total de produção. Além disso, uma aplicação web foi desenvolvida no Software LOGO! Web Editor, integrando esses indicadores. Esta solução possibilitou a monitorização remota dos processos da empresa, com acesso em tempo real pela Internet, garantido pelo endereço IP fixo do controlador e uma senha designada, permitindo que o pessoal autorizado supervisione as operações em qualquer fábrica da empresa.

Em conclusão, a implementação bem sucedida do sistema de monitorização da linha de produção permite agora realizar o tratamento dos dados de produção e abrem novas perspetivas para a tomada de decisões informadas. Por outro lado, o sistema de monitorização fornece informações valiosas sobre as operações da linha de produção, facilitando uma melhor programação da produção, melhorias do processo e promover a melhoria contínua para aumentar a eficiência e a produtividade globais da linha de produção.

Palavras chave: PLC, Lean manufacturing, Automação, Sistema de monitoramento, Aplicação web, Linha de produção, Indústria de pescado

Abstract

The present dissertation focuses on the application of Lean manufacturing principles to address two operational challenges in two production lines of a seafood industrial company. This project was divided into two phases.

The initial scenario of a production line presented significant issues, including production bottlenecks, excessive waiting times, and de-synchronisation between processes and machines.

Through in-depth analysis and process modelling, bottlenecks and inefficiencies were identified. A reverse engineering process was carried out by first developing the graficets that illustrate the functioning of the line by analysing the operation of the line and its controller code. Subsequently, the solutions were implemented in the schematics and the practical phase was carried out on the line.

To address these problems, Lean manufacturing principles and tools based on the research conducted, such as Kaizen, "Standardised work" and Line balancing, were implemented to optimise the cycle time of the production line, reducing waiting times and make the system flow much better and smoother.

The outcomes of the Lean implementation demonstrated a significant improvement in the production of 33.4% and a reduction in production cost per kg of the product of 10,77% in product 1 and a considerable enhancement of 33,2% in production and a reduced production cost of 5,26% in product 2. The objectives sought by the company were successfully achieved without any costs.

The second project of this dissertation aims to develop a Production monitoring system for a cod filleting production line to be able to access remotely and in real-time.

Through the application of a PLC with an integrated web server, a program was initially developed with real-time information on the operation of the cod filleting machine, the total production of this machine that simultaneously produces two fillets of the same cod, the production rate per minute, whether the machine is working or not and the total production time. And, lastly, a web application was developed in LOGO! Web Editor Software, integrating the indicators of the above-mentioned program. The main purpose of this software was to enable remote monitoring of the company's processes, allowing real-time access via the Internet. This access was ensured through the fixed controller's IP address and a designated password, ensuring that authorised staff could remotely supervise operations from the company's internet in any factory.

In conclusion, the successful implementation of the production line monitoring system now makes it possible to collect a high volume of crucial historical and real-time data. This data opens up new possibilities for making informed decisions and the monitoring system provides valuable insights into production line operations, facilitating better production scheduling, process and targeted improvements to increase overall efficiency and productivity of the production line.

Keywords: PLC, Lean manufacturing, Automation, Monitoring system, Web application, Production line, Seafood industry

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Ricardo André Brás Lico

“The greater our knowledge increases, the greater our ignorance unfolds ”

John F. Kennedy

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Abbreviations and Symbols

CCP	Critical Control Point
FBD	Function Block Diagram
HMI	Human-Machine Interface
HTML	HyperText Markup Language
I/O	Input/Output
IP	Internet Protocol
ISA	International Society of Automation
LAD	Ladder Diagram
LWE	LOGO! Web Editor
MAP	Modified Atmosphere Packaging
PDCA	"Plan"-“Do”-“Check”-“Act"
PLC	Programmable Logic Controller
SD	Secure Digital
TDE	Text Display with Ethernet
WLAN	Wireless Local Area Network

Chapter 1

Introduction

This dissertation was conducted as part of the Master's program in Mechanical Engineering at the Faculty of Engineering of the University of Porto. The project occurred during a 4-month internship in the second semester of the 2022/2023 academic year at the company Brasmar in Trofa and Gafanha da Nazaré.

In this chapter, an introduction to the company is made and a detailed description of the project leading to this dissertation is carried out. The present chapter outlines the motivations and objectives of the project and provides an overview of the structure of the dissertation.

1.1 Brasmar

Brasmar is a seafood company based in Portugal that specialises in the production and distribution of a variety of fresh and frozen seafood products. Brasmar is the frozen seafood brand with the greatest diversity in Portugal. With a portfolio of over 200 species, the brand offers products in the categories of fish, seafood, cephalopods, and dried salted cod, soaked and deep-frozen salt cod. The company logo is shown on Figure 1.1.



Figure 1.1: Brasmar logo

The high production capacity, together with the quality and safety of the products, allows the company to export to more than 40 countries and to have commercial delegations in 8 countries around the world: Portugal, Spain, Italy, France, United Kingdom, Norway, Brazil and USA. It

offers a range of value-added services such as packaging, labelling, and distribution. In addition to having a wide selection of seafood products, Brasmar stands out in the market for its specialisation in processing Octopus and Codfish: its star products.

As the result of teamwork and know-how, the Brasmar brand has been awarded by the consumers with the "Flavour of the Year" Seal in the categories of cleaned octopus, loins and soaked codfish slices. The vision of the company is to be, anywhere in the world, a recognised and recommended company in the seafood sector.

The mission now is to be the reference partner of their clients, the pioneers in the offer of new products and packaging forms, recognised for the quality, uniformity and variety of our product range and recognised by the community as a solid, sustainable, environmentally, and socially responsible company. Lastly, the values are to know and enjoy working as a team, to have pride and passion for seafood products, to be responsible and learn from mistakes and to always want to be more and better.

The Brasmar Group has 3 industrial units and 2 commercial units in Portugal. This project was developed in two industrial units, Trofa and Gafanha da Nazaré. The production unit located in Trofa is dedicated to the processing of frozen products of the following categories: fish, soaked cod, cephalopods, shellfish, crustaceans and the composition of fish and seafood preparations. This unit is prepared to receive fresh octopus, from the catch of the day, processing the product from gutting to packaging. It is in this unit that the Brasmar octopus is produced, awarded with the Flavour of the Year label for the 6th consecutive year in Portugal, as well as the soaked cod loins and slices, awarded with the Flavour of the Year label for the 3rd consecutive year.

The other production unit that is located in Gafanha da Nazaré is dedicated to the processing and transformation of salted cod, dry salted cod, as well as cod to the point of salt. This unit is one of the oldest cod dryers in Gafanha da Nazaré and is therefore recognised for the work it has been doing for over 40 years. Since 2018, it has undergone several interventions to restructure and modernise its activity, thus being able to satisfy all the requests of customers.

1.2 Project motivation and description

Brasmar is a company looking for continuous improvement and automation in their production lines in order to further enhance the company in its field and outperform its direct competitors internally and externally.

The project was carried out in the seafood industry as part of the company's maintenance engineering team and the application of Lean manufacturing was studied to help in the resolution of two distinct problems.

The company identified several problems and limitations in the line that made it impossible for it to operate in the long term in a consistent and fluid way to achieve the desired productivity and efficiency and to realise efficient and sustainable resource and production management in pursuit of successful results. This led to the need for the company to try to solve and fix these issues by seeking a concept used in the manufacturing industry called "Lean manufacturing".

This project has very specific constraints because it was carried out in the food industry, particularly in seafood. The knowledge and applications of Lean methodology in this field are very scarce and almost non-existent in this field due to various factors [1]. The major difference between this industry and the vast majority of mass production industries, such as the automotive industry where the application of Lean methodology has been created and most significantly verified, is that these industries consist of a highly systematised, mechanical and mass production.

In the seafood industry, there are several factors that affect the implementation of Lean methodology such as the limited shelf life of products, the seasonal variability of fish, a complex supply chain from fishing to product distribution, diverse handling and processing techniques that require specialised and detailed knowledge, compliance with safety and quality regulations, labour-intensive processes such as fish cleaning, filleting and packaging, and the transportation of products in order to comply with special considerations to maintain freshness and avoid spoilage.

The motivation for this project arose from the identification of production bottlenecks and lack of production supervision issues. From here two projects were considered in the context of the dissertation.

1.3 Objectives of the dissertation

The first project is related to a production line responsible for weighing and packing codfish slices. This is because the line revealed high waiting times in the different stages and a de-synchronisation between processes and machines, requiring process optimisation and automation. For solving this problem a research will be conducted on Lean methodology and tools applied in the manufacturing industry and based on that, are applied in this project in order to maximise the productivity and efficiency of the line to run at the maximum possible speed and achieve higher profits and lower production costs.

The second problem regards a cod filleting production line. This is a production line located in a factory with older machines and without any kind of automation and modernisation looking for progress and improvements in production. In this factory, both this line as the other existing ones, do not have any monitoring system of the production in real-time to be able to analyse the data and improve the processes and systems. From here, the need to create a system that solves this problem was defined. Thus, this project aims to conduct research on the application of production system monitoring in the industrial context. The findings of this research will then be used to implement monitoring techniques in the current project, allowing the operation of the production line to be analysed remotely in real-time and enabling the processing of production data in order to make data-driven decisions that lead to continuous improvement of operations and better productivity and efficiency of processes.

Finally, the goal of this dissertation is to apply the Lean philosophy and its related tools in these two production lines with different purposes to prove that it is possible to implement the Lean methodology and Automation in the food industry, more particularly in the seafood industry.

1.4 Dissertation outline

The dissertation is composed of 5 chapters. Chapter 2 presents a literature review regarding the two problems addressed in this project. For this, Lean methodology applied in industry and Production monitoring systems are surveyed. Additionally, a review of the state of art in each topic is carried out.

Chapter 3 concerns the first problem of the project. Initially, a detailed description of the initial situation is made, followed by an explanation of the application of the state of the art to this problem and subsequently, the solutions implemented. Lastly, the analysis of the results after the implementation of the solutions is carried out and the final conclusions are made.

In Chapter 4, the second project is examined. It begins with a precise representation of the starting point, followed by an exploration of how the research done was applied to address this particular problem. Then, the solutions that were put into action are discussed. Finally, an evaluation of the outcomes resulting from the implementation of these solutions is conducted, leading to the ultimate conclusions.

Lastly, Chapter 5 carries out the final conclusions of the dissertation and future possible works related with the issues addressed in this project.

Chapter 2

Fundamentals and literature review

The current chapter presents, in a methodical manner, the most pertinent aspects and ideas related to the topics of this dissertation.

It will present an explanation about the Lean concept, its history and tools based on this methodology that helped solve the first problem in this project which is the optimisation of the cycle time of a production line in the seafood industry. Therefore, a review of studies will be carried out on the influence of the implementation of the Lean concept in the industry and its contribution to achieving the desired production improvement that can be valuable and relevant to this study.

Lastly, the chapter sets out the concepts and methods that scientifically supported the implementation of the solution for the second problem of this dissertation which allowed the monitoring of a production line. Furthermore, an analysis of existing literature will be conducted regarding a monitoring system and its implementation in a production line.

2.1 Lean methodology

The concept of "Lean" was introduced by Womack, Jones, and Roos in the book "The Machine that Changed the World" [2], is a methodical approach to process improvement and waste reduction in several industries and organisations. It emphasises the optimisation of operations, minimisation of waste and increasing efficiency and productivity of production lines. Various strategies and tools, such as Kaizen, "Standardised work" and Line balancing, are adopted to achieve Lean principles. However, the implementation of Lean can be affected by resistance to change and limited employee involvement in order to achieve innovation. Lastly, the success of the implementation can be evaluated through cycle time, lead time, defect rate and customer satisfaction.

Lean methodologies are being increasingly adopted across diverse industries and Enterprises have benefited from Lean in terms of process improvement, customer satisfaction, and overall success. Lean principles also contribute to economic sustainability by reducing costs, social sustainability by improving working conditions, and environmental sustainability by minimising waste and pollution [3].

2.1.1 Lean tools

Today's businesses need Lean manufacturing to be competitive and to ensure maximum profitability and productivity. The diversity of Lean tools proves to have solutions for the widest range of problems, and businesses are becoming more and more conscious of this, adopting methodologies and methods that seek to gradually reduce waste and adapt their production paradigm to meet market demands.

Implementing Lean tools typically leads to improved product quality, increased production and efficiency, reduced waiting times and greater resource utilisation. It helps eliminate waste through the production line in pursuit of continuous improvement, lowering manufacturing cost and production cycle time and removing bottlenecks [4].

Hence there are many tools available for applying the lean approach and useful particularly for this project.

2.1.1.1 The Kaizen concept

Kaizen is a Japanese concept that emphasises continuous improvement in operations, products, and services. It focuses on reducing cycle time, waste, and variability while improving quality and simplifying operations. It encourages cooperation, employee participation, and ongoing learning. Kaizen is a low-risk strategy with low costs, allowing companies to easily switch back if needed.

The "Plan"- "Do"- "Check"- "Act" (PDCA) four-phase cycle, aligned with Kaizen, provides a structured method for continuous improvement. In the "Plan" phase, goals and objectives are set, and a plan or strategy is developed. The "Do" phase involves implementing the planned changes, monitoring the process, and collecting data and observations. The "Check" phase involves reviewing and assessing the implemented changes against the goals, analysing data, and identifying discrepancies. In the "Act" phase, appropriate measures are taken to address gaps and enhance the process based on the analysis. Lessons learned are considered, and changes are standardised and documented.

In summary, the PDCA cycle, combined with the Kaizen mindset, supports a systematic approach to continuous improvement, ensuring that improvements are planned, implemented, evaluated, and refined for ongoing progress [5, 6].

2.1.1.2 Standardised work

"Standardised work" is a key tool in optimising processes, particularly in manual jobs such as assembly lines. It involves implementing consistent procedures, tools, and ideas to improve outcomes while considering conditions and resources. By standardising work, companies can increase output and reduce rework rates, establishing a logical process that reduces errors and waste. When used alongside other tools from Lean concepts, Standardised work focuses on managing production time, balancing the workforce, improving quality, and reducing costs. The objective is

to achieve high productivity by prioritising efficient activities, optimising processes, reducing production time, and establishing balanced production lines. The goals of Standardised work include eliminating excess inventory, minimising waste, and enhancing overall productivity [7].

2.1.1.3 Line balancing

Line balancing is a Lean manufacturing tool that aims to distribute labour evenly among workstations in a production line, minimising idle time and bottlenecks to improve flow and cycle time. Factors like task variability, worker skills, equipment limitations, and fatigue can impact line balancing effectiveness.

Integration of Line balancing with other Lean tools like Standardised work and Kaizen can further optimise cycle time and overall line efficiency as shown in [8].

Various methods, including linear programming, dynamic programming, heuristic methods, and computer programming, can be employed to achieve an optimised task balance in the production line.

Linear programming is an optimisation technique for solving Line balancing problems, while dynamic programming breaks down large problems into smaller ones. Heuristic methods offer approximations for complex optimisation issues. Computer programming facilitates scenario analysis and optimisation techniques [9].

2.1.2 Lean manufacturing state of art

The research on the implementation of the Lean methodology and its tools in a food processing/packaging production line with the goal of reducing the cycle time through the assembly production line and enhancing the productivity and efficiency of the machines involved was carried out in order to find studies related to this project in different industries which could help and guide this project to find solutions and have success in it.

A previous study conducted by B. Kumar and M. Kumar in 2014 [10] found that the implementation of Standardised work in a production line in an automobile industry has a positive impact on processing time and practices. The research showed that these Lean tools, when combined with Line balancing, lead to a reduction in the cycle time of the production line and the elimination of waste in an assembly plant. This aligns with the objective of the current project, which aims to address the problem of this project by achieving similar improvements in cycle time and contributes to identifying waste time and eliminating it step by step, as a result of proper Line balancing with the help of “Standardised work”.

In their study conducted in 2018, Realyvásquez et al. [11] examined the application of the PDCA Cycle in a production line in the welding industry to reduce the defects in the manufacturing industry. The study demonstrated that it is possible to achieve the desired outcomes by applying the PDCA cycle alongside other Lean tools. The PDCA cycle ensures a continuous improvement process through systematic assessment, implementation, and refinement of changes in order to reach the set goals and objectives. The results of the study showed a significant reduction in

defects and an increase in productivity. These findings provide valuable insights and serve as a reference for the current project, highlighting the effectiveness of the PDCA cycle and lean methodologies in identifying areas to improve and increase production line performance.

The project described in this dissertation aims to promote the Kaizen mindset of continuous improvement and encourage collaboration among operators and different departments. It incorporates various Lean tools based on previous research, which supports the effectiveness of this approach. The implementation of Kaizen practices has been shown to improve quality, reduce cycle time, minimise work-in-process, and increase productivity, as demonstrated by Chan and Tay [8] in 2018. Specific Lean tools such as Line balancing, Standardised layout, and Standardised work have been effectively utilised to accelerate Kaizen implementation, reduce waste, and improve throughput in the printing industry. The study highlights notable increases in production efficiency, with one case experiencing a remarkable 30% improvement and another case showing a significant 13.6% enhancement. These findings emphasise the positive impact of implementing Kaizen and using Lean tools to enhance production efficiency in the printing industry.

Specifically, the current project is focused on a packaging production line, which is consistent with the research conducted by Jadhav and Nachiket [12] in 2021 as their study supports the idea that lean manufacturing techniques like in [8] can be applied across various industries and products to effectively reduce waste associated with the manufacturing process. The research highlighted the effectiveness of lean techniques, such as waste elimination, Standardised work approaches, and Kaizen, in achieving improvements in terms of enhancement, cost reduction, standardisation, and optimisation of assembly cycle time for packaging machines. This highlights the applicability of lean principles in improving efficiency and reducing waste, particularly on a packaging production line like in this project.

In their study, Kumar, Mohan, and Mohanasundaram (2022) focused on the Line balancing of a production line in the garment industry. They showed that Line balancing can be successfully implemented to reduce takt time, cycle time, balancing loss, the number of workstations in lead time, and improve production efficiency. The study also highlighted the benefits of increased overall work efficiency, waste elimination, and reduced human resources [13]. Their findings indicate that Line balancing can be applied in production lines with significant manual work, similar to the scenario in this project, and can serve as a valuable guide to achieve similar outcomes.

The current study aims to achieve energy savings and improve efficiency in a food production line, similar to the findings of a study conducted by Salah and Mustafa. The research highlighted the influence of implementing Lean concepts and tools leading to an increase in production output and a decrease in energy consumption. The study also observed a decrease in wasted time, production waste, and energy consumption. The implementation of Lean methodology and tools like Standardised work and Line balancing explained in this section had a significant impact on improving energy savings by reducing energy consumption within the organization in this study [14].

This research shows that there are not many studies on the implementation of Lean tools in the food processing industry similar to this project. The food industry is a difficult industry to implement new ideas particularly the seafood industry because of the low lifetime of the products

and difficulties in storing products under optimum conditions as quality and safety control are fundamental in the seafood industry. Additionally, the seafood processing industry entails numerous manual tasks that are challenging to automate. The handling and packaging of seafood require special attention and care, making it difficult to achieve high levels of efficiency and standardisation in these stages.

This particular problem stands out due to its two distinct stages in the product's lifecycle: processing and weighing, followed by packaging. These stages require manual work, including weighing the product and carefully placing it in packaging moulds for optimal aesthetics and market appeal. These unique characteristics in the production line present challenges not encountered in other industries, resulting in longer cycle times and inefficiencies. As a consequence, automating and enhancing productivity in these stages, as well as the entire production line becomes more complex. However, there are identical and important studies which served as a guide and basis to develop this project because they are examples with the purpose of reducing the cycle time of the production lines and increasing productivity and efficiency in different industries.

2.2 Production monitoring systems

This section presents the theoretical framework and methodologies adopted to address the second problem in the dissertation, which involves developing a real-time monitoring system for a production process. It includes a literature review on monitoring systems and their application in production lines.

2.2.1 Remote monitoring system

The industrial monitoring operation equipment is composed of industrial computers, PLC programming software, and operational monitoring software. PLC programs are created using the PLC programming software, which is also used to set up the PLC hardware. To guarantee the PLC control equipment is working normally, these programmes are then uploaded or downloaded. On the other hand, the monitoring software configures the operational state of the production line, making it possible to monitor equipment conditions, regulate production parameters, generate production reports, exercise application command control, and share production management data [15].

2.2.1.1 Programmable Logic Controller (PLC)

PLCs are widely used in manufacturing automation due to their flexibility, accuracy, reliability, and real-time performance. They can adapt and modify programming to meet specific requirements, allowing for diverse tasks within manufacturing processes. PLCs excel in precise execution of instructions, enabling accurate control of machinery. They also offer rapid and time-sensitive responses, ensuring efficient and synchronised operations. In control systems, PLCs serve as the main component responsible for data collection from sensors and input devices. They interact with

switches, actuators, motors, and other devices to control the environment securely. PLCs have Ethernet ports for communication with control and monitoring applications, facilitating programming and real-time data exchange [16].

2.2.2 Production monitoring systems state of art

Extensive research was conducted to explore the integration of a monitoring system in production lines across various industries. The aim was to gather insights and guidance that would support the current project in finding effective solutions and achieving successful outcomes.

One influential study conducted by Roque, Torres, and Gonçalves in 2015 [17] demonstrated the effectiveness of an automated monitoring system in enhancing productivity, quality, and flexibility in a paper transformation production line. This study showcased the successful implementation of a database-connected PLC system that collected and stored sensor data, along with a web platform for real-time monitoring and data visualisation serving for example for the application of this project.

In 2015, Mahato et al. [18] conducted relevant research on embedded web PLCs which are low-cost solutions for small automation applications like this project. This reference influenced and helped this research because it highlights the effectiveness of using an embedded PLC for applications involving online data processing, high-speed control, high-speed data logging, and motion control. The presence of a built-in ethernet interface in the embedded web PLC facilitates sharing of production information across industries or enterprises, enabling faster decision-making processes. By embedding a web server in the PLC, the system guarantees the on-time delivery of the necessary information on the shop floor that was pretended by Brasmar's responsables.

In 2018, X. Liu developed a remote monitoring system of PLC equipment based on an embedded Web server as used in this project. This study showed an example of designing the program for monitoring the system and the embedded web server. The PLC was connected to the network and, then it was created a web application for monitoring. The network connection was established between the PLC and the web application, allowing for remote control. The study highlighted a successful implementation of a monitoring system in a production line as it is pretended in this case study [15].

In 2018, Goman and Fedoreev conducted a study focusing on remote training for programming a PLC with an embedded web server. Their research specifically examined a Siemens controller that was equipped with an embedded Web server, which played a central role in their project. The web server provided support for a user-configured page, allowing the user to choose the desired customisation. To monitor the PLC, a web browser was used to establish a connection with the PLC web server, which was assigned a static IP address. First, the session is started, the created web server page is opened, and the results of the program execution are observed. This study served as an illustrative example of designing an embedded web server in a Siemens controller for remote monitoring. The researchers' approach and findings provided valuable insights for this research, particularly in terms of creating and training the system before implementation in the line, simulating and fixing small details to make it work properly in the production line [19].

This research highlights the lack of studies focused on real-time production monitoring systems tailored for the food processing industry, similar to the current project, crucial and comparable studies served as valuable references and foundations for its development. This project presents unique challenges in implementing monitoring systems in the food processing industry, particularly in the seafood industry. The food industry, including seafood processing, faces specific obstacles that make it challenging to introduce new ideas and technologies. One key challenge is the need to maintain optimal conditions for quality and safety control, given the perishable nature of seafood products.

Consequently, the implementation of a monitoring system in this context requires addressing specific considerations, such as dealing with moisture, ensuring precise data collection in wet environments, and dealing with manual intervention during the processing stage. These factors contribute to the complexity of implementing a monitoring system tailored specifically for the food processing industry, requiring careful planning and consideration of the industry's specific requirements.

Despite these challenges, this research is based on relevant studies that provide insights and serve as a guide for the development of the project. These studies demonstrate successful examples of implementing monitoring systems in various industries, showcasing the potential benefits of real-time data collection and analysis. By using these examples, the project aims to overcome the industry-specific challenges and effectively implement a monitoring system in the food processing industry, specifically in the seafood sector.

2.3 Chapter summary

The research on implementing Lean methodology in a food processing/packaging production line aims to reduce cycle time, enhance productivity, and improve efficiency. This project incorporates several Lean tools and concepts, drawing inspiration from various studies. This section provides an explanation of the theoretical concepts that will be applied to address the first problem of the project. Chapter 3 will deeply describe the problem and explain the application of these concepts in the project.

Regarding the second problem developed in this project, proper research has been conducted on the integration of monitoring systems in production lines across diverse industries. Notable studies have focused on developing automated monitoring systems using PLCs. Chapter 4 will detail the second problem of this project and then relate the application of the concepts learnt in the studies described in this chapter to solve the problem.

Chapter 3

Optimisation of the cycle time of a production line

Nowadays, modern manufacturing sectors are increasingly prioritising the need for automation in production lines. Automation will be applied along the production line that will be analysed in this chapter to achieve higher efficiency and productivity and to reduce costs.

3.1 Line description

The purpose of this chapter is to analyse the process of a production line and make the necessary changes to the system and control programs in order to reduce waiting times between processing stations. It will be explained the line operation, what is produced in the production line, how many stations it has and their functions and their interconnections, the sensors present and their roles, the paths that the products follow and where the accumulation of products takes place. Figure 3.1 shows the product processed in this line: codfish slices. The processing goes from the weighing process to the packaging of cod slices as detailed in the next section.



Figure 3.1: Cod slices

3.2 Initial situation

The “Thermoforming” section of the Trofa factory is responsible for the production of ready to distribute codfish packages, it includes the process of weighing, sorting and packaging of the product, as well as conveying parts between stations. Figure 3.2 shows the scheme of the production line and in Table 3.1, the different stages and components of the production line are organised and explained for a better understanding of the scheme.

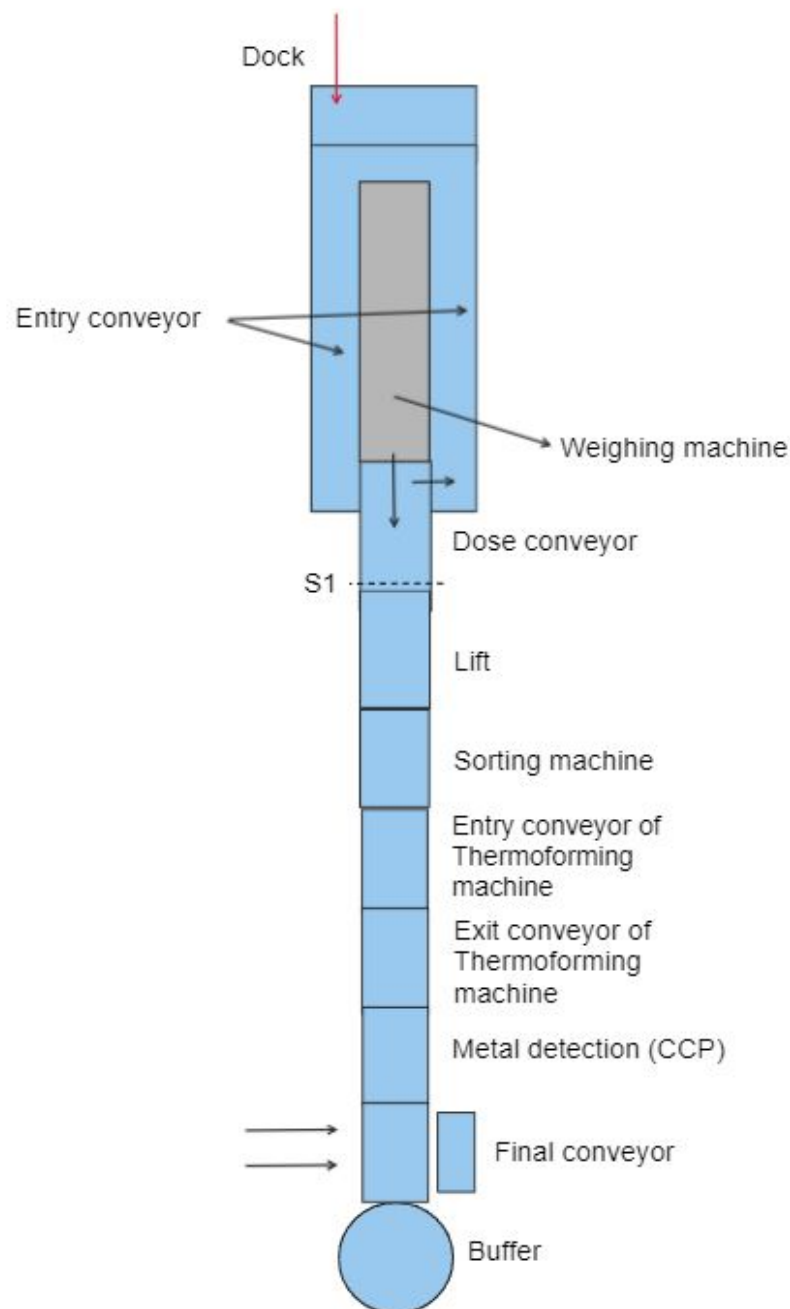


Figure 3.2: Production line scheme

Table 3.1: Definition of variables

Variables	Explanation
Dock	Entry point of the cod slices into the system.
Entry conveyor	Conveyor supplying the operators who put the slices in the Weighing machine; if the slices are rejected this conveyor brings them back to the entry point.
Weighing machine	Weighing machine for codfish slices (When an inlet has the desired weight, the weighing base rotates and drops the codfish slices into the left or right compartment under the inlet and then when required, it drops them onto the Dose conveyor).
Dose conveyor	Dose conveyor from the Weighing machine to the Lift.
Cod slices detector	Sensor detects the cod slices passing from Dose conveyor to the Lift.
Lift	Supply conveyor for the Sorting machine.
Sorting machine	Machine for sorting the slices at the Entry conveyor of Thermoforming machine.
Entry conveyor of Thermoforming machine	Entry conveyor of Thermoforming machine where there are the pre-formed moulds for the codfish packaging.
Thermoforming machine	The machine where the moulds are filled with cod and, in the end, the finished codfish packages come out.
Exit conveyor of Thermoforming machine	Exit conveyor of Thermoforming machine where the packages leave formed and one package at a time goes to the Critical Control Point (holding the other for a few seconds).
Metal detection	Critical Control Point - Metal detection machine.
Final conveyor	Connection conveyor from the CCP to the buffer (Place where packages with a problem detected in the metal detector are expelled by a pneumatic cylinder to a trolley placed next to the conveyor).
Buffer	Station where packages are deposited while workers place them in boxes.

The cod slices start their path on Dock, moving on to the Entry conveyor where operators place the slices in the different inlets of the Weighing machine (Scales) on top of the Dose conveyor for codfish slices (Figure 3.3). In this machine, the weight of the packages of cod is previously defined depending on production. Each package has one dose of cod (weighed quantity of cod) and each dose depending on the product in production can have a different number of slices, for example, 3 to 5 slices per package.

The Weighing machine has seven inlets and each one has two compartments below. First, the operator places a cod slice on one inlet, then it measures the weight of this piece and, it rotates to the counterclockwise or clockwise, storing under it in one of the compartments if it is available and empty. The machine stores the weight and tries to combine the weight of a selection of the fourteen compartments to obtain the product with the correct weight defined previously with a specific tolerance. If the optimum weight cannot be achieved with the cod slices stored in the compartments, the machine unloads some of the compartments to return the cod slices to the beginning so that there is space available for new cod pieces. The slices are sent to Entry conveyor

and returned to repeat the weighing process.

Then, the cod slices move to Dose conveyor where a sensor exists at the end. When this sensor detects the slices, they fall onto Lift and after a short time, it moves forward (Figures 3.4 and 3.5). Dose conveyor sometimes stops with the slices in the middle of the way when the Thermoforming machine is not ready, and it is still in the middle of the cycle and restarts as soon as it can.



Figure 3.3: Production line – Initial part. 1- Dock, 2- Entry conveyor, 3- Weighing machine



Figure 3.4: Production line – Part 2. 1- Return to Entry conveyor, 2- Dose conveyor, 3- Lift

Lift works step by step and it is used to carry the doses from Dose conveyor to the Sorting machine which will arrange the cod pieces on two possible sides on the Entry conveyor of the Thermoforming machine, left or right (Figure 3.6).

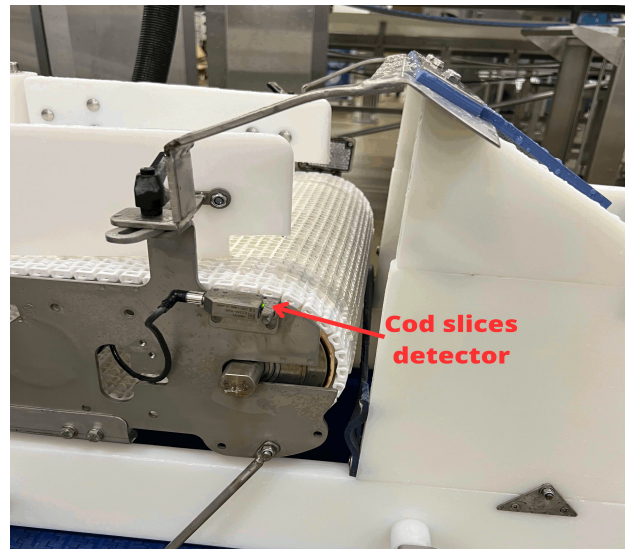


Figure 3.5: Cod slices detector at the Dose conveyor



Figure 3.6: Lift

Each time the conveyor moves forward, the cod pieces drop into the Sorting machine. The Sorting machine has a flap that alternates to the left and right. It first deposits the cod pieces in the right gate and after the Cod slices detector is activated again the flap moves to the other side, waiting for the cod pieces to drop from the conveyor again. After that, if the Thermoforming machine is ready, the right gate opens to deposit the slices in a pre-formed mould and subsequently, a second later the left gate opens to drop into the remaining mould of the Thermoforming machine (Figure 3.7). In this place, workers arrange the cod slices in these moulds for the best formation of the packs.

Afterwards, in the Thermoforming machine (Figure 3.8), the packages are formed by vacuum and heat to obtain the desired shape. Information about the product is placed on the packages.



Figure 3.7: Packaging procedure. 1- Sorting machine, 2- Initial part of Thermoforming machine



Figure 3.8: Final part of Thermoforming machine

This machine is a Variovac Optimus that is used in the food industry for vacuum packaging and modified atmosphere packaging (MAP). The Variovac Optimus machine has several features that make it suitable for industrial food packaging applications such as, high processing speed with the ability to pack up to 10 cycles per minute (20 packages per minute) and, it can handle a wide range of package sizes and shapes.

Afterwards, two packages leave the machine and move from the Exit conveyor of Thermoforming machine. This conveyor allows only one package at a time (holding the other for a few

seconds) to advance to the Critical Control Point, which is the metal detector (Figure 3.9).



Figure 3.9: Exit conveyor of Thermoforming machine (1) and CCP (2)

After the CCP, the packages go to Final conveyor (Figure 3.10). If a problem is detected in the metal detector, the packages are expelled by a pneumatic cylinder to a trolley placed beside the conveyor and, if everything is OK, the package goes to the Buffer, at the end of the production line. In Buffer, several workers organise the packages into boxes ready for delivery.



Figure 3.10: End of the production line. 1- Final conveyor, 2- Buffer, 3 - Trolley

3.3 Qualitative analysis of the production line

After analysing the operation of the production line, it was concluded that the line had several problems and a de-synchronisation between the carried processes. Specifically, there are many

waiting times in the lift waiting for the weighing phase, in the Sorting machine and in the Thermoforming machine. On the other hand, this operating procedure leads to unnecessary pauses in operation and operators standing inactive in the weighing and packaging phases for a considerable period of time for “codfish working parts”. Furthermore, these times lead to more distraction and less willingness to work in the long run because it is not possible to work at an efficient and constant speed. It can be verified that there are long waiting times in the Lift waiting for the product and then in the unloading of this product at the Sorting machine and Thermoforming machine together.

The main problem immediately identified was that the operation of the line depends on the signal from the Thermoforming machine causing delays and high cycle times. The Lift advances only when the Cod slices detector is activated and the production line also stops when the Thermoforming machine is busy or stopped. Because the stages before the Thermoforming machine only work when this machine allows them. It causes other issues, such as sometimes the slices stopping in the middle of the Dose conveyor because the whole system is stopped while the weighing process and the supply conveyor should be running and preparing to supply as soon as it is allowed to proceed.

Another problem found is that the supply system for the Thermoforming machine is providing a dose at a time and this machine is made to work at the rate of 2 to 2 packages, so it has high downtimes waiting for the system to deliver 2 doses for this machine because it is first necessary to carry out the weighing and supply phase. The Thermoforming machine can work at 10 cycles per minute, and it is only working at 5 cycles per minute (10 packages per minute). This problem is caused by another issue in the Sorting machine. This machine is supplied by the Lift when it moves forward. The Sorting machine stores the slices on one side and then waits to be supplied again for the remaining gate. Subsequently, the right gate opens and unloads the slices into the preformed mould. After one second, it drops the slices on the left and the remaining mould. The problem here is that the Sorting machine drops the cod slices alternately and there is a lot of waiting time, especially when the Thermoforming machine is busy or stopped and the rest of the system is waiting for the restart instead of keeping on working. Furthermore, sometimes, while the slices are being dropped, some go into another mould after the correct one (Figure 3.11).

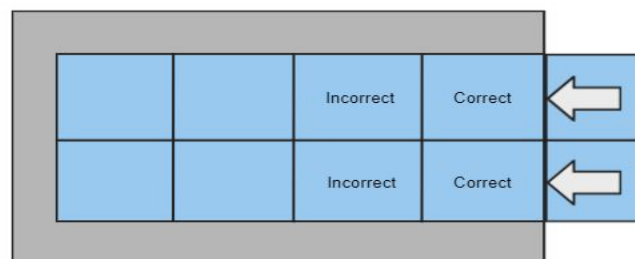


Figure 3.11: Slices waiting at Entry conveyor of Thermoforming machine

The Quantitative Analysis of the initial production line will be shown in Chapter 3.7 to allow an easier analysis and better understanding of the results obtained with the implemented solutions.

3.4 Application of Lean concepts and tools to the production line

Chapter 2 explained some Lean concepts and tools that helped solve and find a solution to optimise the cycle time of a production line in the seafood industry. By adopting a Lean approach, the aim was to maximise efficiency and minimise waste in the production process [8]. This involves identifying bottlenecks, reducing cycle time and improving overall productivity [13]. The project will use various Lean concepts and tools, such as Kaizen, Standardised work and Line balancing, to analyse the current production line, identify areas for improvement and implement changes to reduce cycle time [8, 10, 12, 14]. By applying Lean principles, the project seeks to increase the profit of this seafood production line by increasing productivity and efficiency. In this subsection, it will be explained how these concepts influence the resolution of the problem.

Initially, the project developed followed the Kaizen concept that emphasises continuous improvement and collaboration from all parts involved. According to [8], a Kaizen event is described as an event aimed at continuous improvement, specifically targeting a particular work area and striving to achieve specific goals. This study showed that after applying some Lean tools there is always room for more improvements and better results. It also showed that the workers' collaboration is essential and if they are integrated in the process to find a solution, they will accept the changes easily.

Therefore, the approach to solving this Brasmar project was to keep a mindset of constantly looking for improvement in the ideas that showed up and trying to improve these small details in order to achieve a solution close to perfection. Moreover, different people in the area of Maintenance and Production were asked for their opinion on the major difficulties encountered during production and where the line should be improved in order to understand the problems encountered and show that the collaboration of these people involved is necessary and important to achieve a solution that satisfies and solves the problems encountered [8, 12].

PDCA ("Plan"- "Do"- "Check"- "Act") cycle was used to pursue that objective and was guided by the Kaizen approach [11]. This research showed the application of the PDCA tool to reduce defects and improve the quality and productivity of the production line by following four steps: "Plan", "Do", "Check" and "Act". First, establishing the objectives and plan processes followed by the implementation of the plan and execution of the process. After this, it is studied the actual result and compared against the expected one and, lastly, some corrective actions are done, and the differences are analysed.

The study [11] shows that the PDCA cycle serves as a tool in lean manufacturing projects that aids in identifying improvement opportunities and facilitating their development and implementation in manufacturing projects not necessarily to identify defects like in this study but to identify problems and waste in the production line as it will be explained after and applied in this project.

Based on this study, initially, the goals and objectives in the different stages of the line were set and a plan for solving them was developed. First, it was planned to make the weighing process and the Lift work more efficiently and not depend always on the Thermoforming machine. Moreover, create an operating mode for the line that allows the Sorting machine to supply the Thermoforming machine with two doses by opening both valves simultaneously and also prevents the slices from falling into the wrong moulds. Lastly, create the possibility for the Lift and weighing process to continue running while the Thermoforming machine is busy, and the Sorting machine does not have the two desired doses and the Lift to be supplied with a third dose if it can.

Subsequently, the solutions were implemented and after this stage, the operation of the system was analysed before production and then tested with weights to replicate the product. It reviewed the implemented changes against the expected outcomes and identified the remaining problems.

The implementation of the solutions created some problems that prevented the line from running correctly. The creation of the possibility to supply the third dose led to the problem that the Lift would not have enough time to move forward without receiving an unwanted dose. In addition, by changing the operation of the valves, it prevented the slices from falling safely into the gates and consequently into the moulds, instead, they would damage the moulds.

Lastly, the final measures were taken to solve these small problems and details and the line was tested with normal production leading to the final result.

Thereafter, it is applied another Lean tool named “Standardised work”. This tool was used to standardise the new changes explained in the next section of this chapter [10]. It is necessary to standardise and explain these new changes to all work shifts in Production on this line in order for them to understand the new differences and changes in the way the line operates and new functionalities so that it is possible to achieve the objectives initially set, which was to reduce cycle time and increase the line’s productivity. As [10] explained after implementing the best practices and explaining the correct operating procedure, the operators can better understand their function and through practice improve and perform their work correctly, allowing in the long run to work less time on the production line to produce the same amount previously or produce even more in the same time.

In [12], the benefits of applying Kaizen and “Standardised work” together are demonstrated. As was mentioned earlier in the chapter on the applications of these two tools together in this project, this study explains that by constantly seeking to improve standard operations, it is possible to systematically reduce waste and costs associated with the line leading to the attempt to translate these ideas into the resolution of the problem on the line.

Another tool applied in this project was Line balancing. It was used to identify the production line’s bottlenecks and see areas that could be improved. Based on [10], [13] and [14], initially, the cycle time of the products was calculated, and the time in all stages and between these processes was also measured. The current project was carried out after analysing the production line working for hours to identify bottlenecks and areas for improvement, aiming to minimise these issues and achieve a more balanced and efficient operation of the production line. The objective is to reach

uniformity in operations and improve the distribution of processing times, maximising the use of the resources available by line balancing as mentioned before.

Lastly, in [14] it was studied the implementation of Lean tools like “Standardised work” and Line balancing in order to increase production and decrease energy consumption which are objectives of this project. This study showed that is possible to achieve these results by applying these tools and serving as a background for implementing them in this project leading to reduce time waste and, consequently, at the same time achieving energy savings.

3.5 Quantitative analysis and improvement planning

This project will apply a methodology based on Kaizen, Standardised work and Line balancing tools, as explained in the previous section.

As previously explained in the analysis of the production line, there are many problems caused by the line’s functional logic. It was developed a Grafcet that explains the main functioning of the line (Figure 3.12).

In this project, the production line was simulated in a Computer Software called Flexsim where it was added the times and constraints in each process. It allowed to see and helped identify the bottlenecks and see the differences in production by changing the times in each process. This method helped to identify that the Weighing machine and, mainly, the Lift and Sorting machine connection were the bottlenecks, showing the differences that would make reduce wasted time in these stages of the line with line balancing.

The system was first simulated with the valves operating 1 at a time and an output per hour of 132 products per hour was obtained similar to the production provided by Brasmar (Figure 3.13). It serves as a reliable simulation of the production line, as it was created a production line with all machines and conveyors presented in the line. It includes the times, queues and constraints in and between each process.

On the other hand, a Gantt chart was made with the average times of each process to facilitate the comprehension and identification of the phases to be improved (Figure 3.14).

Afterwards, it was identified first by observing the working line that the signal of the Thermoforming machine was a condition in the stages of the start and positioning of the Lift and the detection of the product. Moreover, the signal of permission for the Thermoforming machine to advance was identified as a condition for the operation of the Lift. So, deleting these conditions it is expected to make the system more independent and able to make things run smoothly.

Furthermore, it was supposed that the insertion of both signals as requirements before opening the gates after the supply conveyor had advanced twice and the Sorting machine was ready to unload two doses in the moulds, would allow the supply system, which is the main bottleneck of the system, to operate independently of the Thermoforming machine until the unloading phase of the products.

Another solution consisted of the possibility of supplying the conveyor a third time after receiving two doses, if the Thermoforming machine was not yet ready, in order to reduce waiting

time and improve synchronisation between the devices. Thus, when the gates can open, they drop the two doses, and the conveyor moves forward immediately.

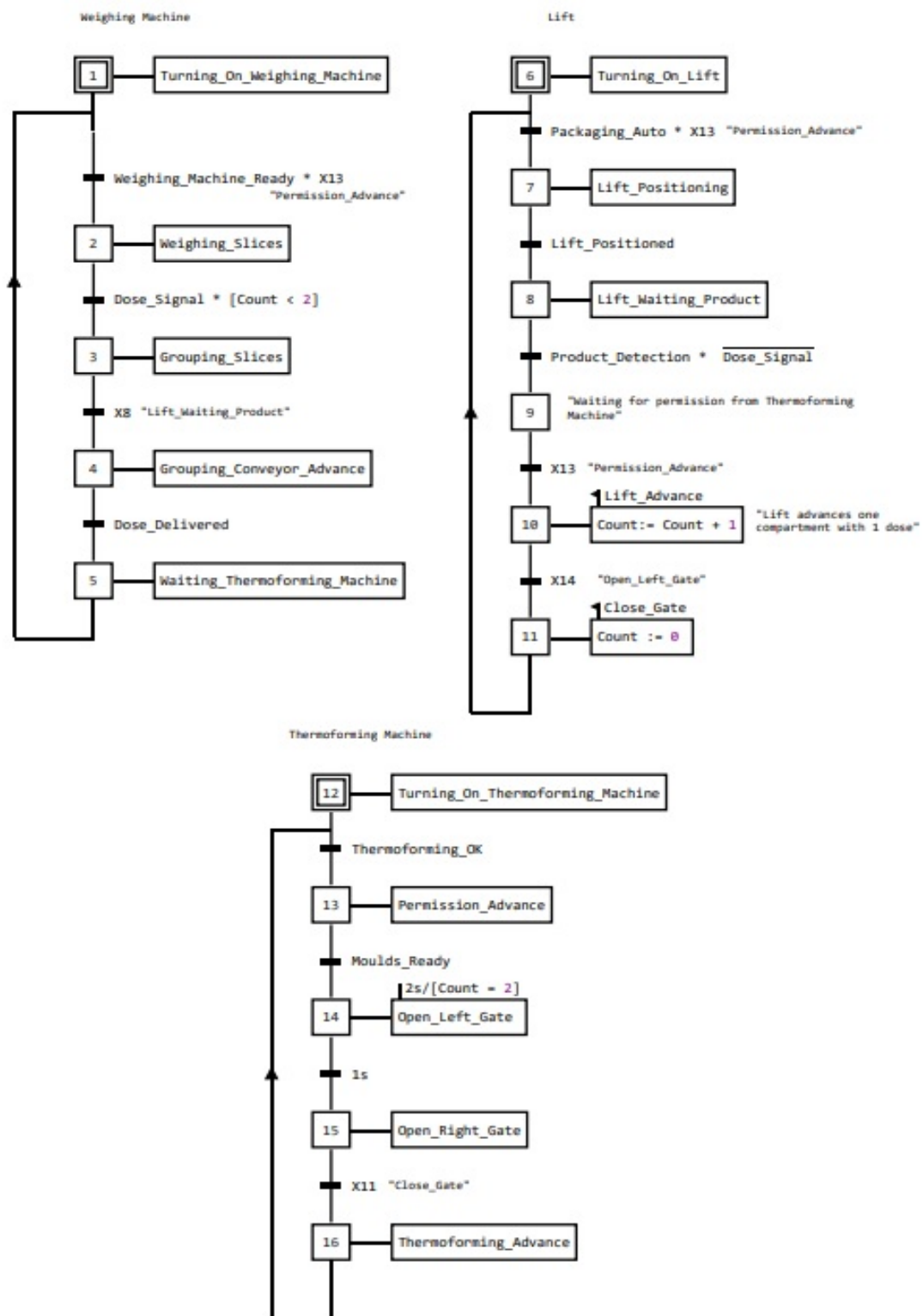


Figure 3.12: Grafcet of initial situation

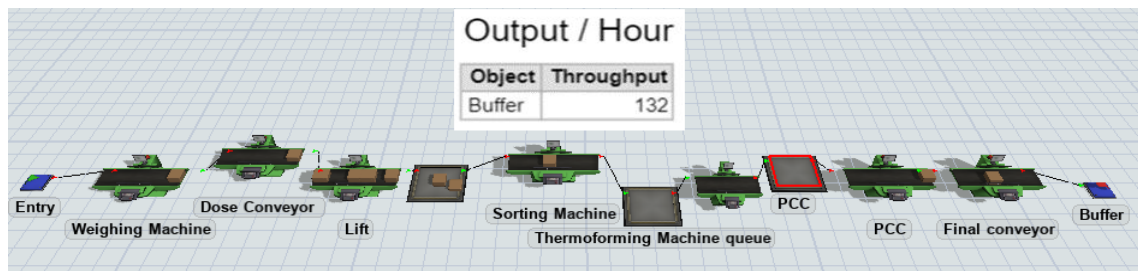


Figure 3.13: Result from simulation and representation in FlexSim

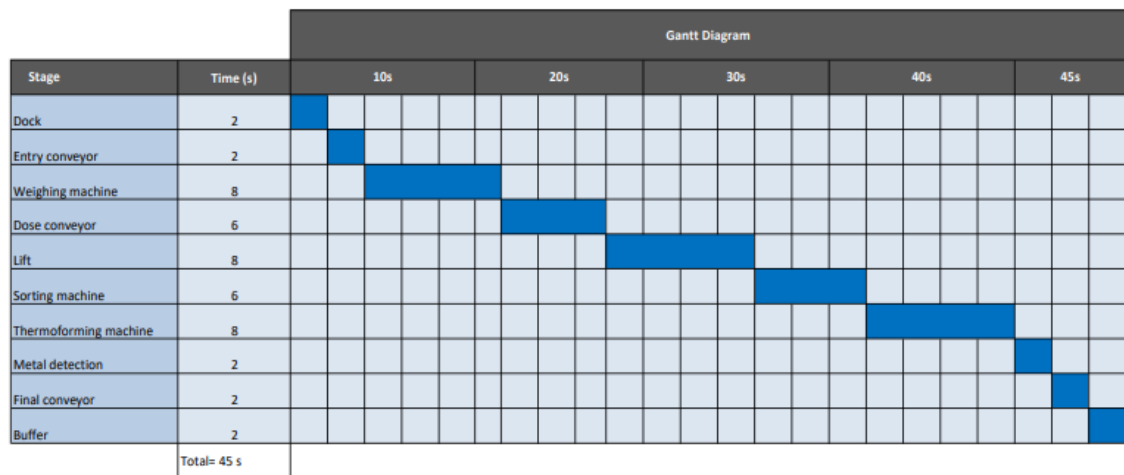


Figure 3.14: Gantt chart of the initial situation

In order to implement this solution, it is necessary to create a memory associated with the Cod slices detector and a new stage is set when the conveyor has already advanced twice and Cod slices detector detects another product. In this situation, the sensor memorises that the product already passed through and the supply conveyor is ready to go forward. After the Thermoforming machine is ready and the gates open, the system already knows that it has the product ready in the supply conveyor and can go forward immediately.

As soon as the system is restarted, all the compartments are already occupied, which will allow the following doses to be much quicker and more effective than before. Because it already has the weight of the slices stored and facilitates the process, this change allows the operator to fill more consistently because the operator doesn't have so many free compartments to fill simultaneously. Thus, in the long term, the fluency and efficiency of the weighing process are greatly improved, allowing the other phases of the system to function better, and organising the distribution of the product cycle time along the entire production line in a better way.

Another change in the system is the operation of the valves related to the gates where the slices are dropped into the Thermoforming machine. The tubes were placed in order for both gates to open and close at the same time instead of opening and closing alternately because the connections of the valves are in parallel. This modification will allow the supply of two doses at the same time to the Thermoforming machine and reduce time in this process.

Afterwards, it was developed a Grafcet based on the initial situation and made the mentioned changes in order to achieve the desired operation of the production line (Figure 3.15).

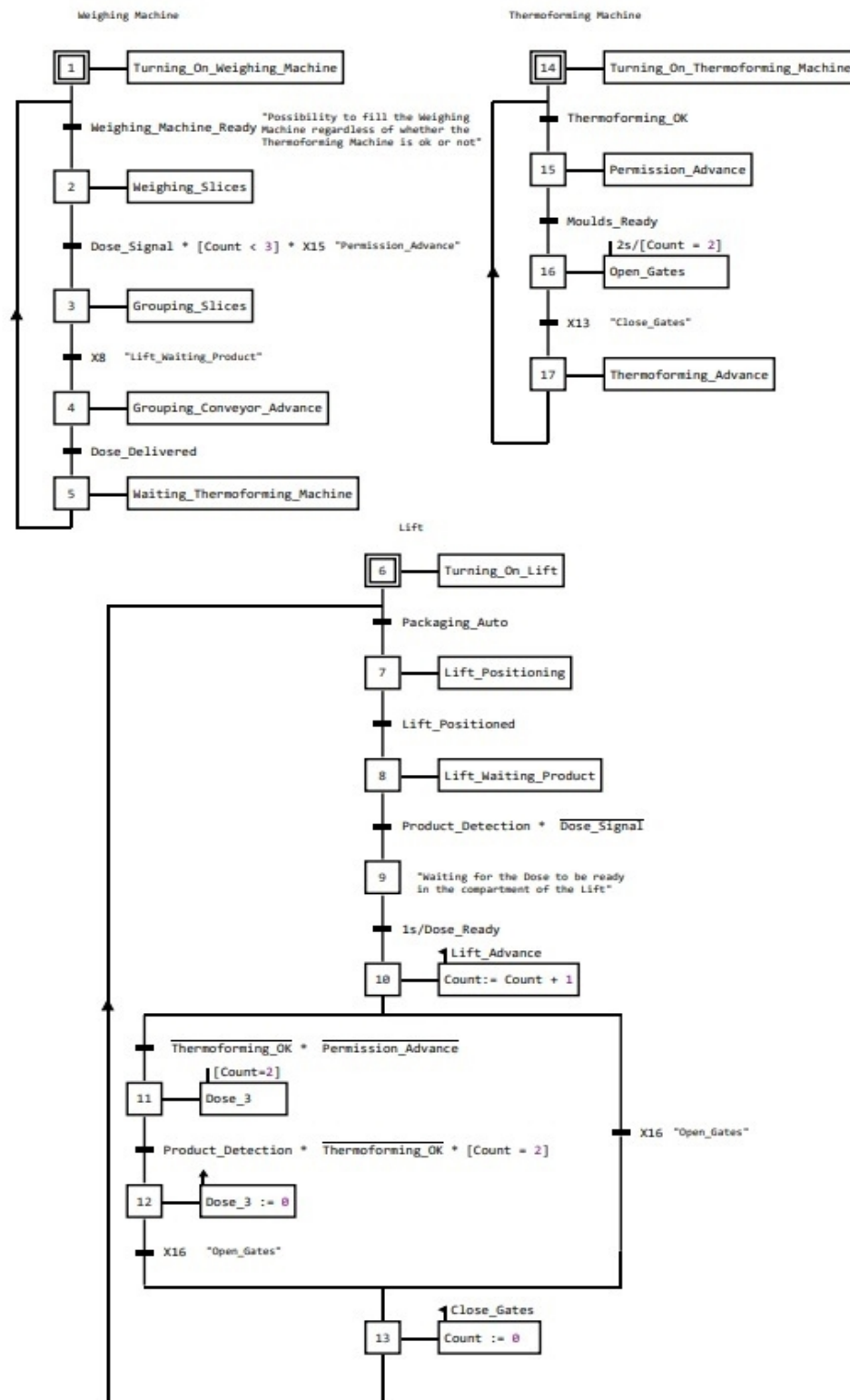


Figure 3.15: Grafcet with the intended changes

These changes were first simulated in the FlexSim, however as the weighing time remains the same, the operating time of the Sorting machine can be longer because it only unloads when two doses are ready and both valves open at the same time, so it needs more time. In the long run, the time of the stages is more uniform, so in the Lift, there can be a waiting time because the doses are ready much faster, and the Thermoforming machine takes the same time as before to form the moulds. But the waiting time in the Thermoforming machine for new doses is much shorter than before. The difference to before is that, as the processes all depended on the Thermoforming machine, they took longer to fill and caused a huge waiting time in the unloading of the doses at the Thermoforming machine, and consequently, in all phases as they could not proceed when Thermoforming machine was busy. So, it was tried to replicate all these ideas and changes in the simulation and production line.

The simulation showed that reducing the waiting times and changing the operating mode of the Lift and Sorting machine will achieve a theoretical but promising 41,67% improvement in production, by producing 187 products per hour (Figure 3.16).

Output / Hour

Object	Throughput
Buffer	187

Figure 3.16: Results from simulation

Lastly, Figure 3.17 shows a Gantt chart with the expected times per process after the changes to the production line, showing an estimated reduction of 13 seconds per product.

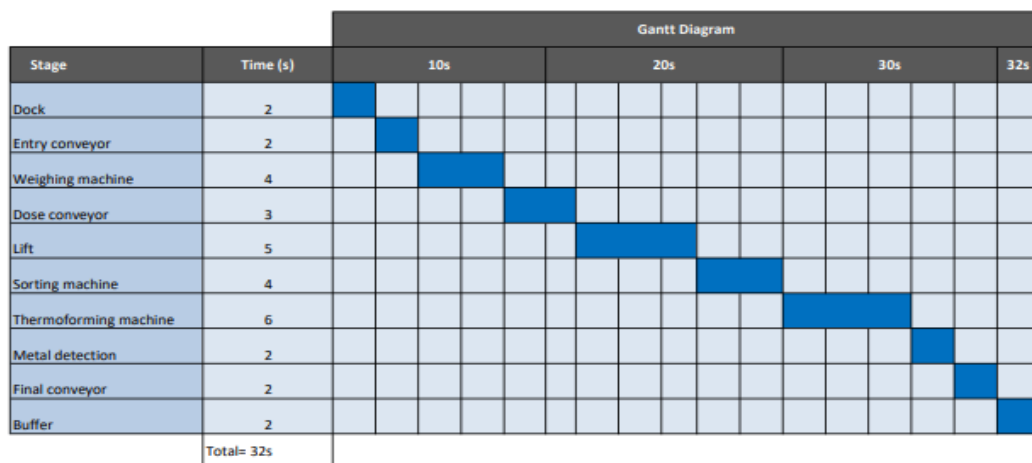


Figure 3.17: Gantt chart with the implemented changes

3.6 Implementing control changes

The next step was to access and analyse the program code running in a PLC line controller (Figure 3.18).



Figure 3.18: MicroLogix 1100

Initially, it was necessary to learn and understand the features and instructions of the Ladder programming language in the software of this controller named “RsLogix 500”.

Afterwards, an overview of all the variables of the Ladder programming language and their context in the program was carried out.

Thereafter, the production line operation was studied from the code perspective, trying to model the whole program in Grafcet in a "reverse engineering" process. Subsequently, it was attempted to identify what was influencing and the meaning of each part present in the program. The electrical circuits were analysed and together with the code was necessary to understand all the connections and signals in the production line.

Lastly, it was studied all options of changes mentioned before in this section to be able to solve the problems. The solution was based on the idea of implementing the changes in the Grafcets drafted and subsequently implementing them in the code.

In the beginning, it was a very confusing code and difficult to understand because the program was prepared by a company hired to develop the project and there was not much background and support in understanding all the variables involved in the program. The logic was not very well elaborated and had many unnecessary and repetitive steps and actions.

Afterwards, it was carried out the intended changes in the code of the PLC and were performed various tests on the line first without products, then with weights and finally in production.

After the implementation of the solutions, it was verified that the creation of the possibility of receiving a third dose if the system is stopped has considerably increased the speed of the production process on the line. In this case, the process is already halfway through, because it

only needs one more dose to have both gates full and ready to unload again. Instead of being forced to wait for the dosing signal to the Weighing machine and having to stand by for one dose to travel to the Lift and still have to hold on for the same process to be repeated again for the second dose. Moreover, now when 3 doses are ready in the Lift (two at the gates and one at the beginning of the Lift), Dose conveyor (responsible for the travel after weighing) it's stopped with another dose ready to be unloaded (Figure 3.19). Basically, after both gates are unloaded it can be ready again much faster than before the implementation of the solutions. Because now it can advance immediately after opening the gates and already has another dose coming, in addition to not having the waiting time for the alternating opening of the gates.



Figure 3.19: Product ready in supply conveyor and another dose already waiting

The introduction of this scenario created a new problem which was that when the gates open, normally the controller sends a signal to the Weighing machine to dose and the issue would arise that the supply conveyor would not have enough time to move forward without receiving another dose. As it already has the third dose ready it is not possible to receive the next one straight away. Therefore, it was necessary to add conditions in order to delay the signal to dose and thus have time for the gates to open and close, the supply conveyor to advance and then the signal would be sent to the Weighing machine and the Dose conveyor would be restarted and finally supply the Lift. When the system is stopped, now the Weighing machine supplies a maximum of 4 doses, and it has the possibility for the operator to continue to fill the machine's 21 compartments in total without stopping the machine as before (Figure 3.20). Before the changes, the operator would have to press a button to stop the weighing process and now, the machine stops the conveyor under it automatically and allows the weighing process to continue while the system is stopped.

The modification of the gate valve's operating mode has improved the production speed of the Thermoforming machine but, due to this change with the old code, the gates were opening too

quickly when the conveyor advanced and it wouldn't give time for the cod slices to drop to the gates safely. So, it was necessary to add a timer to solve this situation and prevent the product from spoiling the moulds or jumping into the wrong one as occurred before. Figure 3.21 shows the gates opening at the same time with this alteration.



Figure 3.20: Weighing machine full



Figure 3.21: Operation of the valves updated

In conclusion, the solutions adopted did not include the addition of new components and involved no costs, although they did address the problems and bottlenecks identified. Now, the Weighing machine and the Lift are no longer the limiting factors of the line as the system has been programmed to be able to run at the fastest speed possible. The operators who are responsible

for organising and correctly placing the slices in the moulds have become the limiting factor, as they cannot perform their function faster and more efficiently at the same time as they do today. Therefore, ideally, the solution was the best possible because it allowed the line to run at the maximum possible speed without any costs and with higher energy savings. In addition, if the company wishes and sees that it is profitable it can assign more labour to the weighing and packaging phases because the line allows it to run faster, enabling larger production quantities to be manufactured in less time.

3.7 Analysis of the results

After the implementation of the solutions detailed in the previous section, there were significant improvements in production outputs.

The analysis based on two different products, a heavier and a lighter product, allowed us to verify a considerable increase in production speed per hour, in less time and lower associated production costs as shown in Tables 3.2 and 3.3.

Table 3.2: Production results of product N°1 before and after the solutions

Product	Production	Normalised costs/kg
N°1 (0,8 kg)	(kg/h)	
Before	101,93	1,0
After	135,97	0,8923

The results of product 1 show a considerable improvement in production of 33,4% and a reduced cost of 10,77%.

Table 3.3: Production results of product N°2 before and after the solutions

Product	Production	Normalised costs/kg
N°2 (1 kg)	(kg/h)	
Before	128,11	1,0
After	170,62	0,9474

In Table 3.3, the findings indicate a significant improvement in production of product 2, with a notable increase of 33,2% and a reduced production cost of 5,26%.

Analysing the values obtained from the production cost maps provided by Brasmar to evaluate the implemented solution, a comparison was made between the values before and after implementation and the real costs per kilogram. These costs are the result of adding the cost of packaging, subsidiary materials, nitrogen costs, general costs, energy used in Weighing and Thermoforming machines and labour.

The simulation predicted a 41,67% improvement in the production and the obtained results were a little lower because the production line in real life is not linear as in the simulation. There

are many variables that could affect the results compared to a simulation like the operators cannot work faster in the weighing process and organising the slices in the moulds so despite the line can work at a higher speed, the operators have a maximum speed limit based on working with the same number of operators. Moreover, the production line can have malfunctions or problems in the Thermoforming machine or the materials for the moulds can run out and have to be changed.

Through the analysis of the results, it can be concluded that the solutions have made it possible to produce more in fewer hours with the same people. Moreover, it created the possibility of producing even more by putting more people to work and producing larger quantities if the need arises. Consequently, the line working for less time to produce the same amount leads to lower energy consumption in the machines and on the line and lower labour costs.

In conclusion, beneficial results were obtained for the company, improving the key variables in production: productivity, efficiency, costs and time. This allowed an increase in production and profits. The objectives sought by the company were successfully achieved, making the Maintenance Engineers satisfied with the solution.

The study proved that the implementation of Lean concepts and tools can reduce cycle times and improve the productivity and efficiency of a production line resulting in the problem being successfully addressed.

3.8 Chapter summary

In brief, the production line had previously shown high waiting times as it alternately supplied the Thermoforming machine with the packs and if this machine was stopped, the system would also stop and wait to be restarted.

Now, with the implementation of the solutions, the system flows much better, allowing the products to flow almost continuously, depending on the signal from the Thermoforming machine only when it has the two doses ready to be unloaded and after this machine has moved forward to be able to dose the Lift again. Moreover, it allows to supply of the two doses simultaneously reducing waiting times in the unloading and it enables the system to continue working if the Thermoforming machine is stopped. Creating the possibility of preparing the two doses to unload and receive a third dose for the following cycle. In addition, it allows the operator to fill all the compartments of the Weighing machine and speed up this process in the long run after restarting the production line, saving effort for the operator, and reducing the bottleneck experienced at this stage with respect to the complete production line.

Lastly, the production results after the implementation of the solutions based on Lean methodology have proven their success and demonstrated a significant increase in production and a reduction in production costs per kg of product, allowing greater profit to be generated and to produce more in less time. The main objectives were achieved and the problem was successfully solved.

Chapter 4

Development of a monitoring system for a production line

The present chapter describes the production process at the beginning of the project in Gafanha da Nazaré, where the operation of the line will be analysed and explained. Later, a solution will be implemented to meet the demands.

The aim of the project is to develop a monitoring production system for a production line of the seafood industry based on a PLC and an embedded web server [15, 18]. Thus, it will require the development of a program to monitor the key parameters of the production line and a web application to display these values [17, 19].

This project includes creating an interface with real-time information from a cod filleting machine, allowing to acquire information about whether the machine is running/shutdown and the throughput of the process, i.e., the output obtained in this production line in a given time (number of fillets per minute). This is the main objective, and it will be explained how it works, what is produced on this production line, how many stations it has and their functions, their interconnections, the paths that the products follow and where the accumulation of products takes place.

4.1 Line description

The value stream mapping of the product of this line is organised into seven stages: reception of raw material, freezing chamber, defrosting stage, vacuum transport to the production line, cod filleting, cleaning, and injection machine.

Initially, the raw material is received at the company (frozen cod) and afterwards, the product is weighed individually before being stored in freezing chambers.

At the defrosting stage, they remove the plastic wrapping from the frozen cod blocks, and these are placed in tanks with treated water to defrost. This process lasts up to 20 hours so that the cod is ready to be scaled and/or salted the next morning.

Subsequently, the cod is transported to the production line through tubes by vacuum. After that, the cod is filleted and the formed fillets are cleaned by employees, who check whether the bones have been properly removed and cut the unnecessary membranes with the help of knives.

Lastly, the fillets are placed in the injector where a solution is applied for the time required to form the "Ponto de Sal" fillet.

This project centers on the cod fillet production stage, where at the beginning of the line one cod comes in and at the end, two resulting fillets come out.

Figure 4.1 shows the scheme of the production line and in Table 4.1, the different phases are organised.

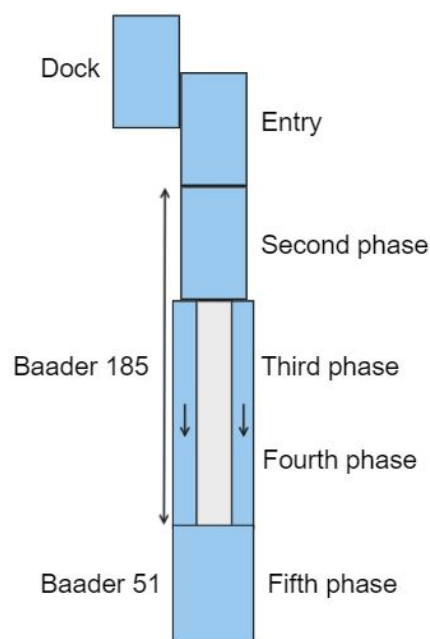


Figure 4.1: Production line scheme

Table 4.1: Phases definition

Stages	Explanation
Entry	The place where workers place the cod with the belly downwards in the filleting machine.
Second phase	The blades separate the fillet from the spine and rib cage of the fish.
Third phase	Cod is cut more deeply, opening the cod more and fillets start to gain shape. Each "fillet" passes through one of two conveyors placed on either side of the machine.
Fourth phase	The blades separate the fillet from the skin and belly bones of the cod, cut off the tail and make two fillets. A fillet is formed on each of the two conveyors.
Fifth phase	The skinning unit of the Baader 51 remove the skin from the fillet with minimal waste.

The filleting machine is a Baader 185 known for producing high-quality fillets with minimum waste. After receiving the codfishes at the Entry, it is responsible for the second, third and fourth phase of the fillet production. The machine is designed to remove as much meat as possible from the bones while minimising damage to the fillet, resulting in a visually appealing, high-quality product. The machine is also highly efficient, with a compact design that allows it to be easily integrated into existing processing lines. It is a popular choice in the fish processing industry and many companies worldwide use it to increase productivity and improve the quality of their products.

Initially, operators cut the head of the fish before the start of the production line, then the cod is placed one by one on the filleting machine with the belly downwards (Figure 4.2). This machine works mechanically, moving the support continuously where the cod is placed.



Figure 4.2: Entry point of cod. 1- Cod positioning

As the fish moves throughout the machine, the cut is made along the back of the fish (the blade is above the fish) and moves towards the tail (Figure 4.3). The cod exerts pressure against the blades leading to the cut. This cut separates the fillet from the spine and the rib cage of the fish.



Figure 4.3: Second phase

After this, it is cut more deeply, forcing the cod to be split and opened, starting to form the two resulting fillets. Each one is directed through one of the two conveyors, which are situated on opposite sides of the machine (Figure 4.4).



Figure 4.4: Third phase

Thereafter, a cut is made along the belly of the fish. This cut separates the fillet from the cod's skin and belly bones which go into a hole between the two conveyors, cuts the tail and makes two fillets (Figure 4.5). A fillet is formed on each of the two conveyors.

At the end, the Baader 51 machine removes the skin from the fillets. The skinning unit uses a rotating drum with rubberized spikes that grip the fillet while it passes over a stationary blade. The blade cuts through the skin while leaving the meat intact, and the skin is then pulled away from the fillet by the drum's spikes (Figure 4.6).



Figure 4.5: Fourth phase. 1- Blades



Figure 4.6: Fifth phase (Baader 51)

The skinning unit of the Baader 51 is highly efficient and can remove the skin from the fillet with minimal waste. The machine is designed to be able to handle a wide range of fish sizes and species, making it a versatile tool in fish processing plants.

4.2 Monitoring requirements for the production line

After analysing the operation of the production line, the production line monitoring system to be set up was proposed as a result of Brasmar's need to obtain real-time, remote information on the operation of the cod filleting production line and to allow access to production data and its processing.

The solution would be based on the installation of an electrical panel with a controller connected to the company's network that would allow the desired information to be obtained. For this to happen, two sensors would have to be installed to count the fillets resulting from each side of the machine in the two conveyors, so the controller would receive the signal from the machine's contactor to be able to know when it is in operation and a button would reset the counters and the time of production measured.

Therefore, the next step was to define location for the installation of the fillet sensors in order to obtain reliable and correct production information and avoid failures during their operation. It was concluded that there is only one area of the production line where it can be effective to place the sensors in each side to count the fillets of cod (Figure 4.7)



Figure 4.7: Area for implementing the fillet sensor

It is necessary to implement two fillet sensors instead of just one because the machine has a compartment separating the two conveyor where the leftovers of the cod from the previous stages of the filleting process go. In order to ensure the accurate counting of fillets and because there may be some phase with a specific problem on one side of the machine such as a poorly cut fish or one that got stuck before the sensor and thus allows to prevent possible errors or minimise the failures in the count than to be using only one sensor to perform the estimated count on both sides.

Due to the inadequate conditions (low temperatures, high humidity and water) for quality and safety control for sensors prior to the process, it is preferable to count the number of fillets accurately after they have been cut and divided into two pieces, rather than when they are still a whole cod. In addition, it needs to be before the last stage at Baader 51 because after that machine

it goes back to inadequate conditions for the fillet sensors and it is a manual work zone to cut the final details of the fillets.

4.3 Applying research results to the problem

Chapter 2 explained some monitoring production systems based on PLCs and embedded web servers that helped solve and find a solution for this problem. In this subsection, it will be explained how these concepts and studies influence the design of a solution for the problem.

Firstly, it was necessary to select a controller for this application and, as explained in [18], embedded web PLCs are an ideal solution because they are low-cost and used for small automation applications similar to this project.

Therefore, a system was developed to acquire and store PLC signals, allowing real-time visualisation through an online application protected by a password within the company's network. The project was guided by the studies such as [15, 17, 18, 19], which detailed the necessary steps to program the PLC for measuring and calculating key parameters, establish network connectivity, and design a web application for displaying these values and facilitating production monitoring and data visualisation in production lines in various industries. These studies served as inspiration throughout the design and implementation phases, contributing to the overall success of this research and helping to achieve a similar and successful monitoring system in this project.

Secondly, the study described in [19], showed the application of a Siemens PLC similar to the one used in this project and demonstrated the importance of creating and testing the system before its implementation on the production line in order to prevent and avoid errors in its operation in production. Therefore, the system of this dissertation was simulated and connected to the computer, simulating objects passing through the two sensors and verifying in the web application if the counting was done correctly, the elapsed time, the machine functioning signal and the reset button worked correctly in real time and were shown in the web page created.

The research developed for this project has demonstrated a scarcity of examples directly related to the food industry however, these studies were considered valuable references and fundamental elements for the development of this project. The implementation of monitoring systems in the food processing industry, especially in the context of seafood, faces specific obstacles that prevent the introduction of new ideas and technologies. The major challenges involve maintaining optimal conditions like low temperatures and high moisture levels for quality and safety control, considering the perishable nature of seafood products. Moreover, it includes accurately collecting data in wet environments and managing potential manual intervention during many processing stages, making it difficult to properly place the systems and acquire accurate and reliable data on their operation. It is extremely important to install the system in a safe place without any risk of it being damaged by water or being influenced and affected in its correct operation by manual labour on the line.

At the light of these challenges and of the lack of comprehensive studies focused on real-time production monitoring systems for the food industry, particularly in the context of seafood

processing, there is an urgent need to address this research gap. This dissertation aims to investigate the feasibility and effectiveness of implementing a monitoring production system that enables the monitoring of production line performance and the analysis of production data in order to enhance the efficiency, quality, and safety of food processing operations. By addressing these critical aspects, this research aims to contribute to the advancement of monitoring systems tailored for the food industry and provide valuable insights for sector professionals, researchers and decision-makers to drive improvements and optimise processes.

4.4 Monitoring system solution

The food processing industry plays a crucial role in meeting the global demand for safe and high-quality food products. As consumer expectations for food safety and efficiency continue to rise, there is an urgent need for monitoring systems that can ensure the functioning of production lines and enable the analysis of production data.

To address the challenges and bridge the existing research gap, a solution has been developed that allows for the monitoring of cod filleting operations and facilitates the analysis of production data. This solution displays real-time information about the operation of the cod filleting machine, the total output of this machine which simultaneously produces two fillets made from the same cod, the production rate per minute, if the machine is working or not and the total time of the production.

The installation location of the two fillet sensors was planned as explained before and they were fixed at the end of the Baader 185 machine before the last phase of the line (Figure 4.8). These fillet detectors allow efficient and fast counting of the cod fillets after shaping in their transition in the machine.

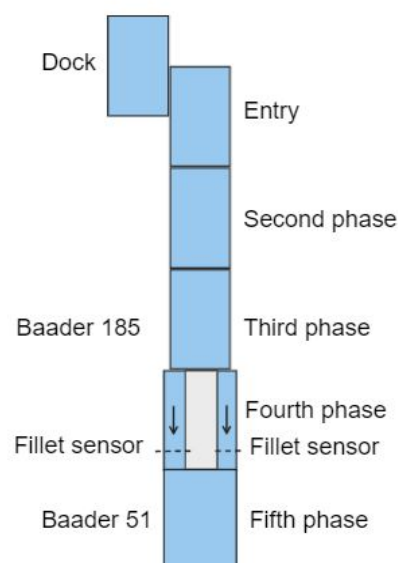


Figure 4.8: Production line schematic with the sensors implemented

After an initial analysis, It was concluded that the installation of the machine and its connections are old-fashioned, being equipment without any automation or connection to the network which made the problem more challenging. It was created an electrical panel independent from the production line due to safety reasons to be able to install the system.

Therefore, to make this solution system possible, some research was made to select a controller to use in the development of this project that would suit the particular conditions in the seafood industry and its restrictions.

4.4.1 Siemens LOGO! 8

For this project, a Siemens LOGO! 8 controller was selected. This is a PLC recommended for small automation projects, it is user-friendly programming and it is recommended for harsh conditions, for example, cold temperatures and 100% relative humidity including condensation and frost like the conditions in this frozen fish industry (Figure 4.9).



Figure 4.9: Siemens LOGO! 8 [20]

Another advantage of using this controller is the integrated web server that makes possible to monitor and control with LOGO! Via WLAN and the Internet, protected by a chosen password and available in all conventional browsers.

LOGO! Soft Comfort, the software responsible for program development, offers user-friendly operation in both single and network modes. In network mode, the configuration process is simple. It allows the display of three programs side-by-side, and signals can be easily dragged and dropped between programs.

The software enables logic functions creation using either the Function Block Diagram (FBD) or Ladder Diagram (LAD) languages. In the network view (graphical representation of the LOGO! modules connected in a network), communication and display are automatically configured, simplifying the setup process. It provides a program simulation, enabling the possibility to test all functional states, parameters and current values during the simulation of the program. This facilitates testing and troubleshooting before implementation.

The LOGO! Web Editor (LWE) is a software designed for creating customised webpages for specific applications. It has a user-friendly web server configuration that does not require HTML programming skills, making it accessible to users without programming backgrounds. Users can easily configure and operate the web server via smartphones, tablets, or computers, with the same interface as the LOGO! 8 or TDE display. To access the remote server, the client simply needs to enter the server's IP address into the web browser on the machine that is already connected to the Internet. In LWE, users can create graphics, integrate texts, images, and links, and simply drag and drop components into the editor area. It supports the display of digital values, switching functions, and display surfaces. Analog values can be displayed as values, analog bars (bar graphs) or analog sliders. The LWE is compatible with common operating systems.

The project data is stored on a micro SD card in LOGO!, and these projects can be further processed in HTML. Additionally, the LOGO! Access Tool enables the storage of data in Excel and facilitates the transfer of process values in real time [21].

4.4.2 Additional components

As mentioned, it was necessary to add two fillet sensors at the final stage of fillet formation to quantify fillet production. In these applications, a photoelectric sensor and mirror to reflect the light beam are commonly used to count products on conveyors due to their accuracy and reliability.

The sensor emits a beam of light and when the beam is interrupted by a passing product, it detects the interruption and counts the product. The mirror system is used to reflect the light beam, allowing the detection of products on both sides of the conveyor. In addition, they are versatile, capable of non-contact sensing and can operate at high speed, as in the application of this project, making them ideal for monitoring systems that require real-time counting.

Based on this knowledge, an Omron E3ZM-R86 sensor was selected because it is a product of a brand known for its high quality and reliability, being compatible with the other components of the system and being recommended for applications of this type with specific conditions related to seafood industry like low temperatures, high humidity and very rigorous cleaning (Figure 4.10). The sensor complies with protection standards IP67 and IP69K.

In addition, the mirror of the same brand E39-R1 compatible with the chosen sensor was selected.

Furthermore, in order to be able to implement the fillet sensors and mirrors on each side of the machine it was necessary to make a support for the sensors and at the same time fix the mirrors in the right position in front of the sensors because it is necessary to be fixed for the safety of the sensors and mirrors due to the passage of the products and the exhaustive cleaning of the line before each production.

Lastly, it was added a button to place next to the start of the machine so that at the end or before the start of production it is pressed to reset the total counted fillet value and the elapsed time from the last production.



Figure 4.10: Omron E3ZM-R86 sensor installed

4.5 Implementation of the solution

The signal from the main contactor of the Baader 185 and the signals from the two fillet sensors added were connected to the controller in order to obtain the desired data.

A button has been installed to be able to reset the total fillet counter and the production timer.

Figure 4.11 shows the I/O scheme of the PLC implemented in the line and the table 4.2 explains these variables.

Table 4.2: I/O variables

Inputs	Explanation
I1	Aux contact of the main contactor of the Baader 185.
I2	Button for resetting the timer and counter of cod fillets.
I3	Sensor for the cod fillet detection (Left belt).
I4	Sensor for the cod fillet detection (Right belt).

Furthermore, an electrical panel had to be created and a 24V power supply, relay and controller were installed.

The circuit installation of the machine had no network connection, as described earlier, so it was necessary to create a network point and connect it to the PLC (Figure 4.12). Because the purpose is to create an interface to be accessed remotely and monitor the machine's production and information when desired.

The program was developed in Siemens software "LOGO!Soft Comfort V8.3" recommended for Siemens LOGO! controller. In the program, a counter was created to quantify the number of fillets produced being updated every minute, a counter for the total number of fillets, a timer after the start of production on the line, a signal to obtain information on whether the machine is

running or not and a button that resets the counter responsible for the total number of fillets and the timer for starting a new production (Figure 4.13).

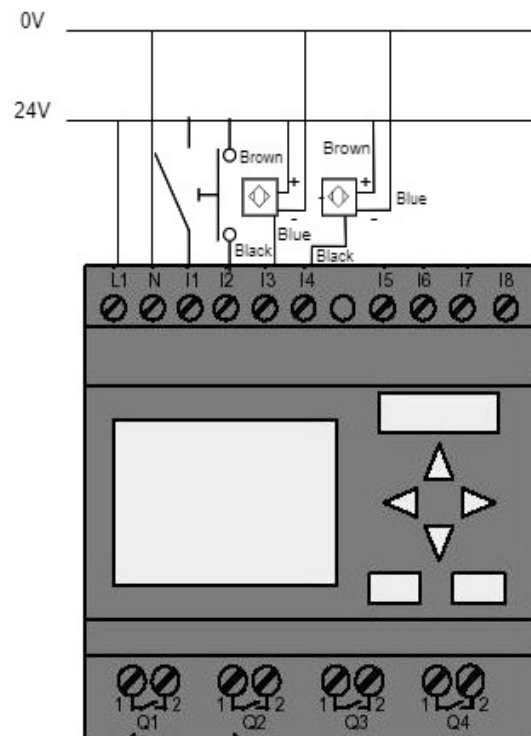


Figure 4.11: I/O scheme of the PLC

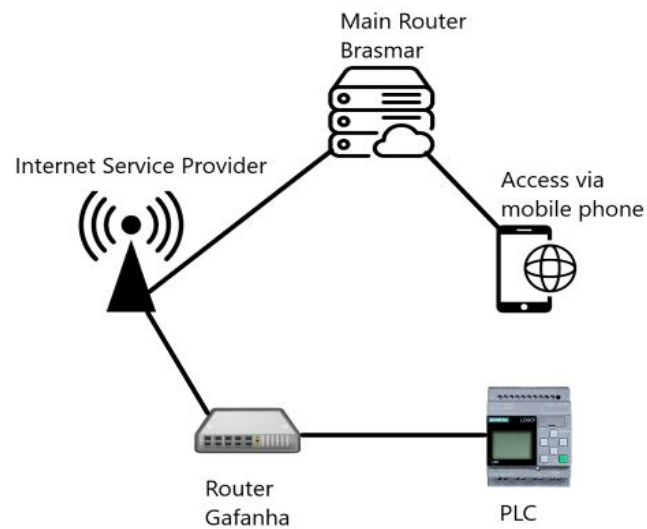


Figure 4.12: PLC connection to the Brasmar network

Afterwards, an application was created in LWE Software with the program indicators mentioned above in order to be able to monitor processes remotely in the company allowing access via the internet in real-time with the fixed controller's IP and a chosen password (Figure 4.14).

Figure 4.14: Access to web application

Furthermore, an Excel file associated with the LOGO! controller was created to have access to the same indicators in this format, perform the calculation of the production rate automatically, and have access to all production data. It is possible to have access to synchronised data variables of the LOGO! controller in real-time or generate log files with the historical information on each variable, allowing an analysis of the production values of this line and to be able to better plan and correct possible problems during the production.

Lastly, a manual for the utilisation of the web application and excel file was created and provided to the Company.

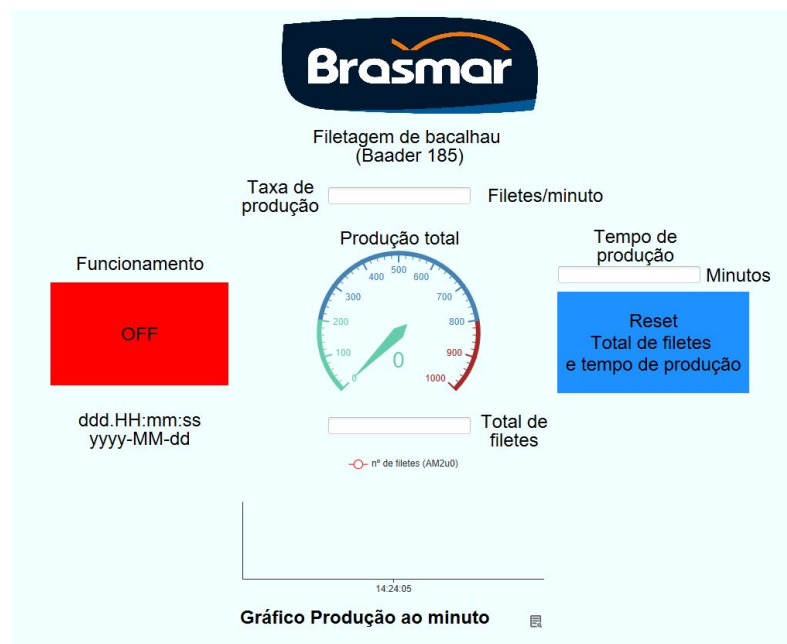


Figure 4.15: Web application design for cod filleting machine

4.6 Analysis of the results

The implementation of the production line monitoring system was successfully achieved, and now it becomes possible to gather crucial historical and real-time information about the production line and utilise the collected data to make informed decisions. It will provide valuable insights into the functioning of the production line, enabling better scheduling of production, process improvement, and implementing targeted improvements to enhance overall efficiency and productivity.

Through the analysis of the results, it can be concluded that the ability to monitor and analyse production data empowers food industry engineers to make data-driven decisions and drive continuous improvement in their operations and the solution has made it possible to monitor the line remotely and in real-time.

In conclusion, beneficial results were obtained for the company, improving the digitalisation in this particular factory, and enabling access to variables in production: productivity, efficiency, time and, consequently, costs of production. The objectives sought by the company were successfully achieved, making the Maintenance Engineers satisfied with the solution.

The study proved that the implementation of the concepts analysed in the research can enable the monitoring of a production line and calculate variables related to the productivity and efficiency of a production line, resulting in the successful resolution of the problem.

4.7 Chapter summary

In brief, the company Brasmar needed a system to monitor remotely and in real-time a cod filleting production line to gather information about the production on this line.

Now, with the implementation of the solutions, the system provides information on the operation of the production line, the number of fillets produced and the elapsed production time. This will allow the Production Engineers to analyse production data on the line, leading to better planning of the production, better decision-making, and better control of the line in order to achieve higher profits. The aim is to continuously improve the productivity and efficiency of this production line.

Lastly, the implementation of the solution was successfully done, and the main objectives were achieved as the company desired.

Chapter 5

Conclusions and Future perspectives

5.1 Conclusions

This dissertation provided a comprehensive study of the application of Lean methodology in the seafood industry. The research conducted for this study highlighted the scarcity of studies exploring the integration of Lean tools in the seafood processing industry. However, the application of Lean manufacturing and its related tools was successfully demonstrated in this project carried out in the company Brasmar from the seafood industry.

It is important to recognise that the application of Lean in the seafood industry will not come without its challenges. The unique characteristics of seafood, including perishability and seasonality, present distinct hurdles that require tailored approaches to implement lean effectively. In addition, the seafood industry demands handling and processing techniques that require specialised and comprehensive knowledge, compliance with strict safety and quality regulations and the industry's demanding labour-intensive processes. Thus, careful planning, adaptability, continuous improvement culture and ongoing monitoring are vital to overcoming these obstacles and ensuring sustainable success.

Through an in-depth analysis of a seafood production line, it was shown the significant benefits that lean principles and tools can contribute to this specific area. The findings of this study have revealed that the adoption of lean practices in the seafood industry can lead to remarkable improvements in efficiency, cost-effectiveness, and overall operational performance in a production line. By eliminating waste, reducing cycle times, and optimising resource utilisation, lean methodologies have demonstrated their potential to enhance productivity and profitability for seafood businesses and, in particular, for this production line of codfish.

On the other hand, the successful implementation of a monitoring system for a production line can provide valuable insights to help inspect the operation of a production line and analyse production data, enabling improved production planning and better decision-making to enhance productivity and efficiency in the production process through ongoing improvements.

In conclusion, the main objectives for both problems were achieved, and the research findings

demonstrated that the significant advantages of incorporating Lean implementation and Automation in the seafood industry have the potential to drive deep and impactful change, boosting the industry into a new era of efficiency and success. These methodologies, when properly adapted to address the specific challenges of the industry, can lead to a revolutionary change in the way seafood companies operate and thrive in an ever-evolving global market.

The most challenging part of this project was carrying out all phases of the project from analysis, testing or the implementation of the solutions in line with production, i.e., it depended on when the line was running to be able to analyse and when it was stopped to be able to test and implement solutions, varying according to the work demand on different days and weeks. In addition, most of the time was spent at the Trofa plant, which made it impossible to analyse the line in operation for a long time or to be able to see it working in Gafanha da Nazaré depending on the production and be able to implement the solutions when desired.

This project provided the possibility to grow at a personal and professional level, acquiring different skills particularly learning to operate and programme in PLCs of different brands and knowing how to approach and solve problems of this type in an industry. In addition, it provided an enriching experience in a company and factory environment.

For Brasmar, the result was a 33% improvement in production on the first problem line and the development of the production line monitoring system at Gafanha da Nazaré, enabling its control and production data analysis.

5.2 Future perspectives

For future perspectives, the methods used to solve the first problem can be adopted in any line present in the factory by analysing the operation of the line, developing solutions to solve the problems identified and implementing them, since the majority also have their problems and it is always possible to try to improve and search for new solutions. In addition, the monitoring system proved to be very valuable for the company and could serve as a basis for implementation in the other lines in order to improve their productivity and efficiency to make the factory and, consequently, Brasmar an increasingly modern, automated and digital company in search of continuous improvement.

As future researchers and industry professionals build on these findings, it is predicted that the seafood sector will continue to experience transformative improvements, leading to a more efficient, resilient and environmentally responsible industry.

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