INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO

MESTRADO EM ENGENHARIA MECÂNICA

AUMENTO DO RENDIMENTO DE BLOCOS DE CORTIÇA E MELHORIA DO FLUXO DE DADOS NUMA EMPRESA LÍDER NO SECTOR DA CORTIÇA

MIGUEL FERREIRA PINTO

outubro de 2023

POLITÉCNICO
DO PORTO

INCREASING CORK BLOCK YIELD AND IMPROVING DATA FLOW IN A LEADING COMPANY IN THE CORK SECTOR

Miguel Ferreira Pinto

2023

Instituto Superior de Engenharia do Porto

Departamento de Engenharia Mecânica

P.PORTO

INCREASING CORK BLOCK YIELD AND IMPROVING DATA FLOW IN A LEADING COMPANY IN THE CORK SECTOR

Miguel Ferreira Pinto

1170552

Dissertation presented to School of Engineering to fulfill the requirements necessary to obtain a Master's degree in Mechanical Engineering, carried out under the guidance of professor José Carlos Vieira De Sá.

2023

Instituto Superior de Engenharia do Porto

Departamento de Engenharia Mecânica

P.PORTO

ACKNOWLEDGEMENTS

I want to offer my sincere thanks to my family, friends, and mentors for their unflagging support, inspiration, and direction while I worked to finish my thesis. I owe them a debt of gratitude since their excellent contributions have been crucial to my academic and personal development.

I want to start by expressing my sincere gratitude to my wonderful family. I can't describe how grateful I am to my parents, whose love, sacrifices, and faith in my skills have served as my continual inspiration and drive. My success has been based on your unfailing support and encouragement, and I will always be appreciative of the possibilities you have given me.

My good friends have been my pillars of support throughout this trip, and I am incredibly thankful to them. I've always found strength and inspiration in your companionship, and I'm grateful to have you by my side.

For their important advice and mentorship throughout my thesis, my academic advisers José Carlos Vieira De Sá from the university and Rui Moreira from the corporation deserve my sincere gratitude. Your knowledge, insight, and willingness to devote time and resources to guiding my study were crucial to its successful conclusion. Your consistent encouragement, helpful criticism, and academic rigor have substantially improved the caliber of my work.

página propositadamente em branco

ABSTRACT

The cork block production sector faces a pressing challenge due to suboptimal yield rates compounded by inadequate loss indicators and information flow inefficiencies. This thesis addresses the central question: "How can we enhance the equipment, tools, and human resources involved in cork block production?" Employing an action-research methodology, this study delves into these issues with the overarching goal of significantly improving cork block yields and optimizing communication among industry stakeholders.

The study's findings are two-fold, emphasizing its original contributions. Firstly, it identifies substantial enhancements in information dissemination and data utilization. Notably, the research achieves remarkable improvements in block yield rates, introduces innovative mold refurbishment and reconstruction techniques, and implements a novel tool for effective deviation control. These outcomes underscore the study's significance and represent a pivotal contribution to advancing cork block manufacturing and transformation.

Of unique importance is the fusion of academic knowledge with practical application in an authentic industrial setting. Collaboration with seasoned industry professionals highlights the value of applied research and underscores the author's unwavering commitment to industrial engineering. In summary, this study underscores the tangible benefits of elevating production output and fortifying information flow within industrial processes, thereby fostering growth within the cork block production sector. The integration of Lean 4.0 principles underscores the forward-looking approach taken in this research, aligning with the evolving needs of the industry. Nevertheless, it is important to acknowledge certain limitations, including the specificity of the study's context and the need for further validation in diverse industrial settings.

KEYWORDS

Lean Management; Yield; Flow; Process; Data; Cork

página propositadamente em branco

RESUMO

O sector da produção de blocos de cortiça enfrenta um desafio premente devido a taxas de rendimento subóptimas, agravadas por indicadores de perda inadequados e ineficiências no fluxo de informação. Esta tese aborda a questão central: "Como podemos melhorar o equipamento, as ferramentas e os recursos humanos envolvidos na produção de blocos de cortiça?" Empregando uma metodologia de investigação-ação, este estudo aprofunda estas questões com o objetivo global de melhorar significativamente o rendimento dos blocos de cortiça e otimizar a comunicação entre as partes interessadas da indústria.

As conclusões do estudo são de dois tipos, enfatizando as suas contribuições originais. Em primeiro lugar, identifica melhorias substanciais na disseminação da informação e na utilização de dados. Em particular, a investigação consegue melhorias notáveis nas taxas de rendimento dos blocos, introduz técnicas inovadoras de renovação e reconstrução de moldes e implementa uma nova ferramenta para um controlo eficaz dos desvios. Estes resultados sublinham a importância do estudo e representam um contributo fundamental para o avanço do fabrico e transformação de blocos de cortiça.

De importância única é a fusão do conhecimento académico com a aplicação prática num ambiente industrial autêntico. A colaboração com profissionais experientes da indústria realça o valor da investigação aplicada e sublinha o empenho inabalável do autor na engenharia industrial. Em resumo, este estudo sublinha os benefícios tangíveis de elevar a produção e fortalecer o fluxo de informação nos processos industriais, promovendo assim o crescimento no sector da produção de blocos de cortiça. A integração dos princípios Lean 4.0 sublinha a abordagem orientada para o futuro adoptada nesta investigação, alinhada com as necessidades em evolução da indústria. No entanto, é importante reconhecer algumas limitações, incluindo a especificidade do contexto do estudo e a necessidade de validação adicional em diversos contextos industriais

PALAVRAS-CHAVE

Lean Management; Yield; Flow; Process; Data; Cork

página propositadamente em branco

INDEX

página propositadamente em branco

FIGURES INDEX

página propositadamente em branco

TABLES INDEX

página propositadamente em branco

LIST OF ABBREVIATIONS AND SYMBOLS

List of abbreviations

6M's	Manpower; Material; Machines; Methods; Measurements; Mother Nature
AGL	Agglomeration
AI	Artificial Intelligence
AR	Augmented Reality
BI	Business Intelligence
CC	Cloud Computing
CPS	Cyber Physical System
ERP	Enterprise Resource Planning
EVA	Ethylene Vinyl Acetate
GM	Gross Margin
I4.0	Industry 4.0
IoS	Internet of Services
IoT	Internet of Things
ISEP	Instituto Superior de Engenharia do Porto
IU 3	Industrial Unit 3
KPIs	Key Performance Indicators
MES	Manufacturing Execution System
MIT	Massachusetts Institute of Technology
mm	Millimeters
MO	Manufacturing Order
OPL's	One Point Lessons
P.Porto	Politécnico do Porto
PDCA	Plan-Do-Check-Act
P&L	Profit and Losses
SMED	Single Minute Exchange od Dies
TPM	Total Productive Maintenance
TPS	Toyota Production System
TRF	Transformation
TRW	Thompson Ramo Wooldridge
VSM	Value Stream Mapping

página propositadamente em branco

1. INTRODUCTION

The persistent search of efficiency, sustainability, and superior quality is what drives the pursuit of operational excellence across industry borders in the dynamic world of modern manufacturing. This thesis sets out on a transformational journey within the specific field of cork block manufacturing, a sector famous for its special problems and untapped innovative potential. This research, which is firmly grounded in the two pillars of Lean Management and Industry 4.0 integration, reveals prospects that resonate with real, substantial value improvements, setting a standard for excellence across industries.

Following this, I present my master's thesis, which details my internship experience in a cork company, a world leader in cork manufacturing, from October 6, 2022, to May 31, 2023, as part of the Dissertation/Project/Internship (DPEST) course unit for the Master of Mechanical Engineering in Industrial Management at the Instituto Superior de Engenharia do Porto.

The context for the subjects addressed in this dissertation, as well as its relevance and goals, are provided in this chapter. Furthermore, the research approach and document structure will be discussed.

1.1. Contextualization

When it comes to process modernization and, as a result, competitive evolution, company growth has grown tremendously over time. These issues, which are brought on by development demands, affect every industrial sector[1].

It is becoming more and more challenging to succeed in such a turbulent, uncertain, complex, and ambiguous world given this very competitive corporate climate. Therefore, it's more important than ever for businesses to figure out how to boost productivity, improve product quality, and cut expenses all at once [2]. In order to do this, they have started working on digital transformation and modernizing industrial systems, which are frequently linked to the idea of Industry 4.0.

With this technological revolution, issues with information flow inside businesses, standardization of manufacturing techniques, and inventory variations between physical inventory and system inventory all occur. To achieve the necessary continual improvement, it is crucial to optimize and develop processes and tools. In order to help senior management with the control and management of production, this paper will present and create techniques to enhance the flow of information based on Industry 4.0 and Lean techniques, and the analysis and development of indicators and tools to assist the top management.

It is imperative to have an increase in production capacity, a decrease in waste and production deviations, and a cognitive shift in the operators' understanding of how to properly insert and handle data during production.

Since the current yield is insufficient, this effort will concentrate on the area of converting blocks into slabs (Transformation area). It is hoped that by increasing yield in this area, it will be able to meet demand, correct errors, and cover associated expenditures.

Therefore, the purpose of this article is to propose strategies for enhancing information flow that are based on Industry 4.0 and the Lean concept, data analysis, and deviation control discovered during production.

1.2. Company Presentation

This project was carried out in a leading company in the cork industry. Thus, this chapter provides an overview of a pioneering company in the field of sustainable material solutions. With a rich heritage and a history deeply rooted in the cork industry, the company has emerged as a global leader in the development and production of innovative composite materials. It is inserted in a group of companies with around 27 000 clients, 10 raw material industrial units, 18 industrial units, and 51 distribution firms worldwide, it is currently the largest cork transformation organization in the world [3].

The company is driven by a mission to create sustainable, high-performance solutions that contribute to a better and more sustainable world. It envisions a future where composite materials play a significant role in various industries, replacing conventional materials with eco-friendly alternatives that deliver superior performance.

The company in question, established in 1963, is a subsidiary which has grown in significance within the business throughout time. Its goal is to recycle and create new products using only natural and organic resources. The cork that is not used by the cork stopper industry is used as a raw material to create materials for a variety of industries, including construction, home and office decoration, design, and functional items that bring cork closer to the end user, as well as high-tech industries like the automotive, aerospace, and aeronautics. Thus, the company contributes significantly to the value addition of cork through innovation and distinctiveness.

The organization has a number of vital skills that help it maintain its position as a market leader. A devoted staff with specialized knowledge, innovative production techniques, research and innovation facilities, quality assurance systems, and competence in the creation of composite materials are a few examples of these skills. The business has continually provided high-quality products and solutions by utilizing these competencies.

Next, its industrial units will be presented in Figure 1.

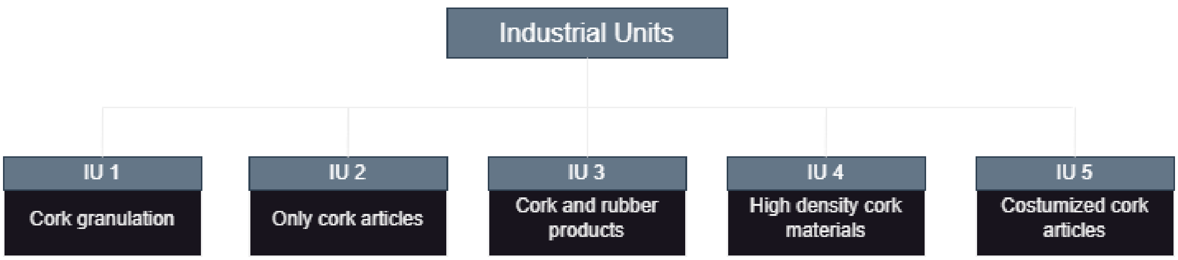


Figure 1 - Company's Industrial Units

1.3. Objectives and Thesis Relevance

The company's plan calls for improving the caliber of production data with a special emphasis in the field of cork and rubber composites blocks transformation. This is required because yield between production and consumption has shown unsatisfactory values recently, resulting in negative gross margin financial outcomes and issues with current inventory. These outcomes are a result of mistakes in data collection and insertion, a dearth of performance indicators in production, and a lack of tools to identify deviations and problems across the board for the management team of the cork-rubber composites (IU 3) area. In order to comprehend the work done in the factory and weak places where action may be possible, it is therefore expected that an action will be taken in the study of variances between consumption and daily production. Therefore, a project will be managed to raise yield in the area, where it is anticipated that improvement measures will increase yield in the research area through planning and management.

The different stages of the project are described below:

1. integration in the IU 3 area and familiarization with the production process (agglomeration and transformation).
2. Monitoring of production activities and collection of faults that prevent the correct insertion of data.
3. Transformation area yield project follow-up and application of Lean tools and overall improvements.
4. Development of tools that improve and assist the area in controlling production.
5. Applying the tools.

Performing and analyzing the project's tools and its impact.

1.4. Research Methodology

The Action-Research research method was selected in order to most effectively achieve the stated aim and objective. Essentially, Action-Research is a participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes, grounded in a participatory worldview. It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities[4].

Action-Research, which Kurt Lewin first popularized in the 1930s, was inspired by the need for a research strategy that could integrate theoretical and practical situations. Thus, we can distinguish between two goals: one focuses on practice intervention, while the other is knowledge development from problem solving[5].

This strategy, by definition, generates an activity that seeks to alter reality and results in changes as a result of the action. The process is repeated if these alterations are unacceptable[6].

There are five main categories in which to categorize this research process. There is potential for a diagnostic phase in the beginning, where the issue needs to be located. The strategy must then be devised, and steps must be developed in an action planning phase in order to best solve the problem being studied. As a result, during the "Action Taking" phase, the plans made during the preceding phase are carried out. The effects and outcomes of the activities taken are examined in the fourth phase, which is referred to as "Evaluating". The success of the activities taken in light of the outcomes should then be evaluated in a concluding phase, entitled “Specifying Learning”[7].

These categories can be seen in the following figure:

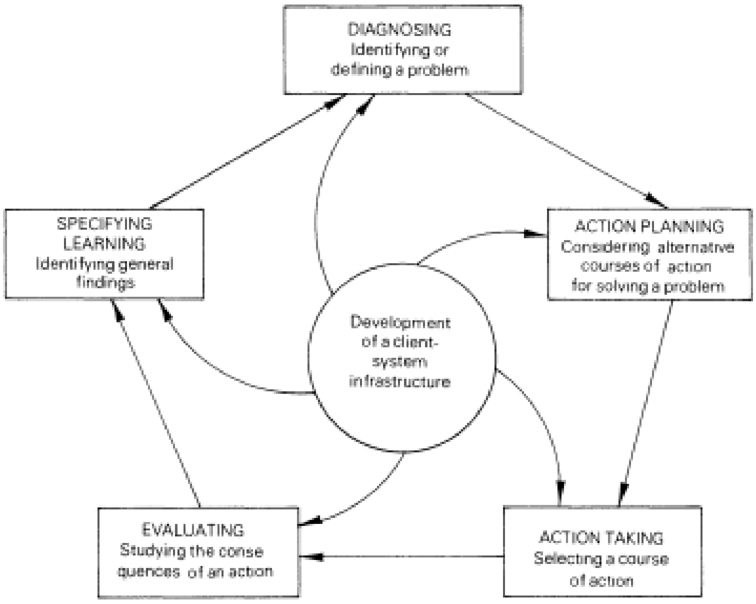


Figure 2 - The cyclical process of action research[7].

The problem or issue that needed to be resolved was first recognized in this project in order to make sure that it was precise, manageable, and pertinent to the situation. The action plan was then created, with specifics for the first item, taking into account the challenges we would encounter as soon as we joined the organization. The next stage involved gathering and analyzing data in order to better determine the action plan required for the topic-related improvement ideas. Finally, it's critical to continuously evaluate and track the actions made in order to confirm their actual results.

1.5. Thesis Structure

The report's structure mainly consists of four parts: this introduction, which introduces the reader to the dissertation's theme, its goals, and the approach taken to meet those goals. Additionally, a preliminary assessment of the literature will be conducted with the goal of familiarizing the reader with the subjects raised in this work by examining the technological and scientific advancements that have been published in books and scientific papers specifically devoted to the topic. A third section that deals with the development of the practical work will come after this, and it will refer to the solutions discovered, the projects created, as well as the handling and critical analysis of the outcomes. Finally, conclusions are reached and fresh directions for future growth are suggested.

2. STATE OF THE ART

This chapter intends to show the results of these and how they might serve as a basis for the approach employed in this report in order to introduce the work topics and analyze what effects they have had on other comparable projects.

2.1. Industry 4.0

The use of Industry 4.0 as a strategic instrument in the industry's effort to address quality issues in cork block production is of significant importance. Industry 4.0 is a revolution in manufacturing, where connection and digitalization have a significant impact on how products are produced. In establishing this initial link between Industry 4.0 and quality, it is critical to recognize that adoption of these cutting-edge technologies presents a potential to significantly raise quality standards as well as a means of technical evolution.

A more proactive and accurate approach to quality is made possible by Industry 4.0. Early detection of quality deviations is made possible by sophisticated sensors and real-time monitoring systems, avoiding defects and maximizing compliance with quality requirements. Large-scale data analysis also offers a greater comprehension of the factors that influence quality, allowing for the optimization of processes for dependable, high-quality outcomes.

As demonstrated in [8], which examined whether employees perceive the impact of Industry 4.0 on quality management and demonstrates how technology can be a potent ally in the continuous improvement, we will investigate how Industry 4.0 and quality can be inextricably intertwined. Forging a path that not only addresses quality issues but also elevates the manufacturing of cork blocks to an exceptional level will need building this bridge between Industry 4.0 and quality.

2.1.1. Concept

The quick adaptability of production and the level of global competition today are important contributors to the constantly shifting market demands. This is only possible because manufacturing technology has made considerable advancements. Industry 4.0 is a potential strategy that focuses on integrating all value chain participants as well as business and manufacturing processes (suppliers and customers)[9].

Industry 4.0 (I4.0), referred as 4th Industrial Revolution, also known as “smart manufacturing”, “integrated industry” or “industrial internet”, is considered to be the answer for the increasing requirements and complexity in the manufacturing industry in recent years. Companies face significant hurdles as a result of factors such intensifying global rivalry, rising market instability, demand for more customized products, and reduced product life cycles[10].

The core concept was initially presented at the Hannover exhibition in 2011 by Henning Kagermann and was given the moniker "Industry 4.0" after the "Industrie 4.0" industrial plan in Germany, and since then it has served as a benchmark for businesses all across the world[11,12]. The German government supported this program, which served to solidify Germany's status as one of the top producers of machinery and automobiles worldwide[9].

In Figure 3, we can see the different concepts inherent in Industry 4.0.

Figure 3 - Industry 4.0[13]

This idea is essentially a revolution that applies the ideas of cyber-physical systems (CPS), the internet and future-oriented technologies, as well as intelligent systems with improved paradigms for human-machine interaction. Another way to put it is that this ideology represents the ability of the industrial components to communicate with one another [14].

This technological growth has benefited business in a variety of ways, including the development of fresh ideas like digitalization, the Internet of Things (IoT), and Cyber-Physical Systems, which have become important within the sector [15]. Pinto [16], writes that establishing implementation techniques that are specific to each type of firm is important to accomplish an adequate transition to an integrated production and management system.

This theme is centered on the digital transformation of manufacturing processes, which encompasses a number of associations, including Big Data Analysis (BD), organization, and Artificial Intelligence (AI). The goal is to transition from Industry 3.0, where machinery was automated and controlled individually by computers, to a system that can gather and transform data from tools and machinery in order to produce intelligent and automatic judgments[17].

Historical perspective of different industrial revolutions is presented in Figure4.

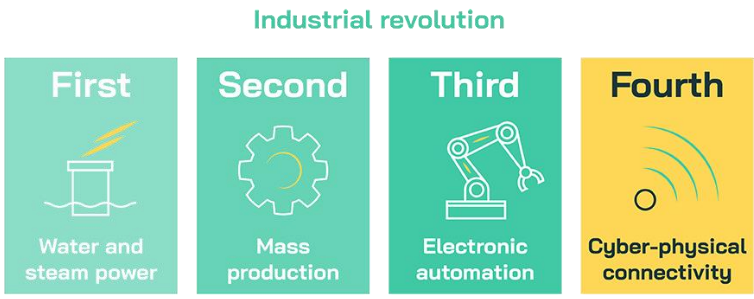


Figure 4 - Historical perspective of industrial revolutions [18]

The Table 1 is intended to present some concepts and definitions in the area.

Table 1 – Different concepts and definitions in Industry 4.0

Reference	Concept Description
[19]	The primary goal of Industry 4.0 is the development of digital manufacturing, also known as the "smart" factory, which entails smart networking, mobility, flexibility of industrial operations and their interoperability, integration with customers and suppliers, and the adoption of novel business models. Intelligent networks built on cyber-physical systems are what the fourth industrial revolution is known for.
[20]	The use of cutting-edge digital technology is promoted with the aim of enhancing human interaction with products and machinery, enhancing productivity, and enhancing work. efficiency. Therefore, depending on the acquired data, these man-machine production systems may enhance the reconfiguration utilizing both virtual and physical representations. and genuine ones. This suggests that the majority of low-skilled positions have been replaced with positions that are more sophisticated and place a higher value on interaction.
[21]	One may argue that up until 2017, research was mostly focused on machines without taking into account the function of humans. The operator, however, was incorporated as a crucial component of the system as the subject and knowledge evolved. The management of industrial processes and the accomplishment of specific and strategic tasks still heavily rely on human labor. In addition to the data that operators may acquire in order to assist with work and interact with intelligent systems, they can also produce data in order to train equipment and improve process flows.
[22]	The concept "Industry 4.0" refers to the fourth industrial revolution, which is characterized by a new degree of organization and control over the whole value chain of a product's life cycle and is focused on meeting the needs of customers who are becoming more and more individual. Industry 4.0's primary goal is to satisfy specific client demands, which has an impact on order administration, R&D, factory commissioning, delivery, product use, and recycling.
[18]	The fourth industrial revolution recommends more strongly connected businesses and nations globally through supply chains and sensor networks, encouraging the notion of autonomous factories and promoting the emergence of global understanding along this line day by day.

2.1.2. Industry 4.0 Principles and Technologies

It is claimed that Industry 4.0 represents a new paradigm for intelligent and autonomous manufacturing. It more deeply integrates communication, information, and intelligence technologies with manufacturing operations systems[23].

In accordance with Ibarra, [24], the fundamental guidelines for effective implementation are Interoperability, Virtualization, Decentralization of decision making, Real-time capability, Service orientation and Modularity. These design principles support companies in identifying possible Industry 4.0 pilots, which then can be implemented.

We shall address each of these in the sentences that follow.

Interoperability

A key enabler of Industry 4.0 is interoperability. CPS and people are connected via the IoT and IoS in Industry 4.0 businesses. For the CPS of different manufacturers to communicate with one another, standards will be essential [24].

Virtualization

Because of virtualization, CPS can keep an eye on physical processes. These sensor data are connected to simulation and virtual plant models. As a result, a virtual representation of the real world is made [25].

Decentralization

Decentralized techniques, as opposed to centralized ones, shift decision-making authority to the components of the production system. Without the aid of a more advanced control unit, these production system components are capable of making decisions on their own [26]. Nevertheless, it is essential to monitor the entire system at all times for quality control and traceability.

Real-time capability

Data collection and analysis must be done in real time for organizational tasks. By doing this, the plant's condition is continuously monitored and evaluated. As a result, the plant can respond to a machine failure by rerouting products to a different machine[25].

Service Orientation

Other participants can use the services provided by businesses, CPS, and people over the IoS. They may be made available both inside and outside of the organization[25].

Depending on Moghaddam [27] , the actions or tasks that make up a service may be provided by numerous parties across the value network, and they may be carried out using a variety of resources, including human labor, technical systems, information, consumables, land, and other resources.

Modularity

Other participants can use the services provided by businesses, CPS, and people over the IoS. They may be made available both inside and outside of the organization. As a result, modular systems are simple to modify in the event of seasonal changes or altered product qualities[25,28].

Industry 4.0 can provide manufacturing organizations with viable business models, increased productivity, higher quality, and better working conditions, among its many other benefits. It has received a lot of interest from academics and practitioners because of these potential benefits. The decision to adopt and evaluate has proven difficult due to drawbacks such a lack of awareness, costs, modifications to existing systems, and potential energy drawbacks.[29].

According to Bai [29], Physical and digital technologies can be used to categorize its technology. Physical technologies typically refer to equipment used in manufacturing, such as sensors and drones or additive manufacturing. Modern information and communication technologies including cloud computing, big data analytics, and simulation are considered to be examples of digital technology.

Figure 5 following is an illustration of Industry 4.0 technologies [30].

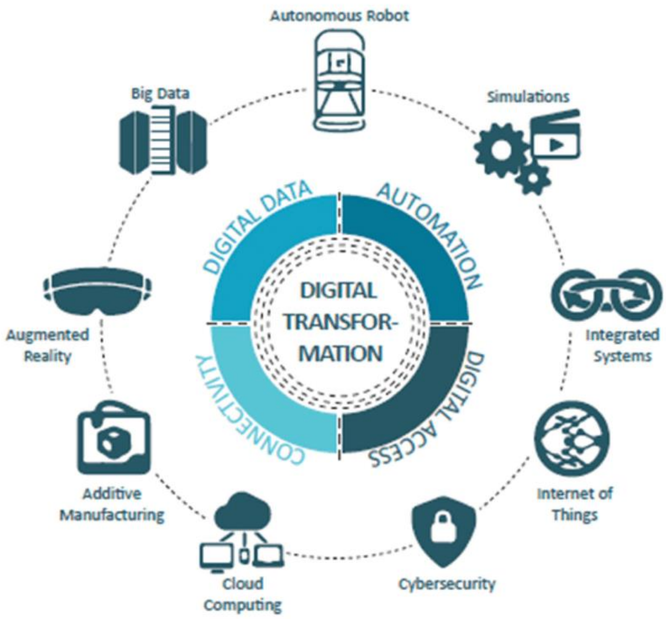


Figure 5 - Industry 4.0 Technologies [31]

The Internet of Things

The term "Internet of Things" refers to the network of physical objects, including machines, vehicles, buildings, and other objects, that are connected to the internet and equipped with sensors, software, and network connectivity. These items can connect to and communicate with other internet-enabled devices and systems as well as with one another thanks to the IoT, which enables them to carry out a range of jobs and functions automatically or with little to no human involvement[18,32].

As stated by Xu [33], The Internet of Things is built on a worldwide network architecture made up of multiple linked devices that rely on technology for sensing, communicating, networking, and processing information.

Smart appliances, connected autos, wearable fitness trackers, and smart thermostats are a few IoT gadget types. These gadgets collect and communicate data via connectivity and sensors for a range of uses, including enhancing energy efficiency, monitoring and analyzing personal health data, and automating numerous processes and chores.

Numerous industries and sectors, including manufacturing, transportation, healthcare, agriculture, and energy, stand to benefit from the IoT. Predictive maintenance systems, smart cities, and connected homes are just a few examples of the additional services and applications it can offer. IoT device expansion also prompts worries about security, privacy, and the handling of massive volumes of data [34].

Figure 6 below shows the main IoT concepts.

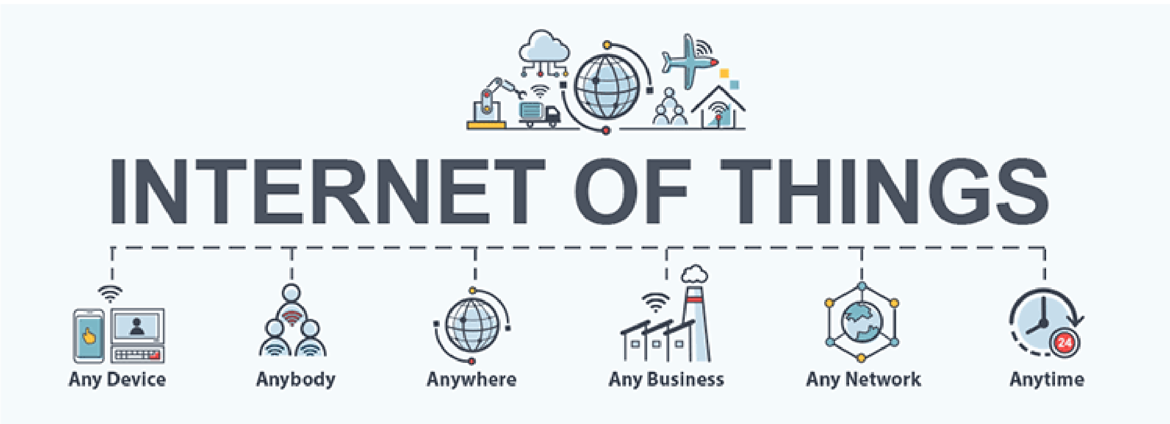


Figure 6 - Internet of Things[35]

Big Data and Analytics

Large, complicated datasets that are challenging to analyze using conventional data processing tools and methodologies are referred to as "big data." These datasets can originate from a range of sources, including social media, sensors, and transactional data, and are frequently created by corporations and organizations as part of their regular operations[36]. Big data can be difficult to manage and analyze because of its amount, diversity, and velocity, but it can also give organizations useful insights and allow them to make data-driven decisions.

Thus, big data analytics is the act of analyzing enormous and complicated databases to find patterns, trends, and relationships, often with the aim of enhancing company performance and decision-making. In order to extract actionable insights, this process includes gathering, storing, and preparing the data for analysis as well as using statistical, machine learning, and other analytical approaches. Numerous industries, including marketing, finance, healthcare, and manufacturing, can benefit from big data analytics[37].

Diverse types of Big Data and Analytics fields can be seen in Figure 7.

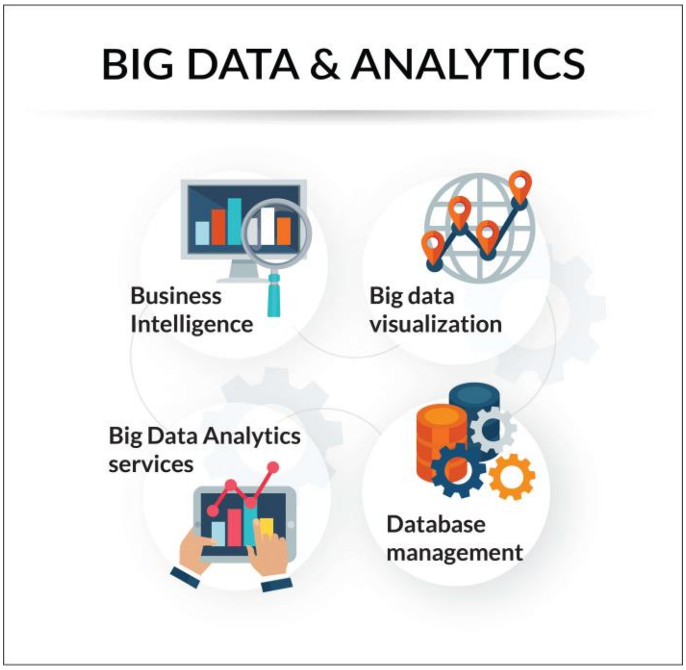


Figure 7 - Big Data and Analytics[38]

Cloud Computing

A computing model known as "cloud computing"(CC), Figure 8, makes use of the internet to supply shared computing resources such servers, storage, networking, software, analytics, and intelligence (the cloud). Users can remotely use these resources via a cloud provider to process and store data instead of using local servers or personal devices.

In this sense, a cloud system may be capable of running anything, from common word processors to specially created business tools created and developed for an organization. By enhancing flexibility, lowering costs, increasing elasticity, and maximizing resource use, cloud computing has been attributed with boosting competitiveness[39].

The most popular cloud computing platforms include *Google Drive, Windows Azure*, and *BlueCloud* [40].

Figure 8 - Cloud Computing[41]

Integrated Systems

An integrated system is made up of various parts or subsystems that cooperate to carry out a certain task or function. An integrated system, in the context of technology, is often a computer system or network that comprises hardware, software, and other components that are intended to operate in unison.

A variety of applications, including those in business, manufacturing, healthcare, transportation, and many other areas, use integrated systems. By automating tasks and procedures, they are frequently utilized to increase productivity, lower errors, and streamline operations.

Manufacturing execution systems (MES), which integrate and optimize production processes in a manufacturing environment, and enterprise resource planning (ERP) systems, which integrate and manage various business processes like accounting, inventory management, and human resources, are examples of integrated systems.

Integrated systems can assist firms in meeting regulatory requirements and enhancing compliance with industry standards in addition to their many practical advantages.

Simulation

Industry 4.0 systems and processes can be designed, tested, and optimized using the potent instrument of simulation. Engineers and designers can assess and improve the performance of complicated systems and processes before they are created or put into use by constructing virtual models of them. This enables the creation of more effective and efficient solutions by assisting in the identification of possible issues and bottlenecks [42].

For Industry 4.0 applications, there are many different kinds of simulation tools and software available, ranging from basic spreadsheet-based tools to sophisticated, multi-physics modeling platforms. Numerous industrial processes and systems, such as those involved in manufacturing, logistics, supply chain management, and energy systems, can be simulated using these technologies [43]. Regarding logistics and procurement management and the implementation of Lean techniques, in [44], it was possible to reduce the time needed to locate consumables by around 70%, promote improvements in stock control and reduce the time needed to replenish materials.

Overall, simulation is crucial to the development and application of Industry 4.0 technologies, assisting businesses in streamlining their processes and enhancing the effectiveness and efficiency of their systems.

Additive Manufacturing

A manufacturing technique called additive manufacturing, sometimes referred to as 3D printing, involves piling up layers of material to create three-dimensional items. By allowing for more design flexibility, quicker production times, and decreased waste, it has the potential to completely transform conventional manufacturing processes.

To produce a more adaptable and effective production process within the context of Industry 4.0, additive manufacturing can be integrated into advanced manufacturing systems. For instance, manufacturers can employ additive manufacturing to make unique parts on demand, allowing them to lower inventory and streamline their supply chain. Additionally, it can be utilized to create intricate, highly accurate pieces that would be challenging or impossible to make with conventional techniques [45].

It is crucial to combine additive manufacturing with other cutting-edge technologies, such as the Internet of Things (IoT), artificial intelligence (AI), and machine learning, in order to fully exploit the potential of additive manufacturing in an Industry 4.0 context. This may make it possible to monitor and manage the manufacturing process in real-time, as well as analyze and improve output in real-time [46].

Overall, the integration of Industry 4.0 technologies and additive manufacturing has the potential to drastically alter current manufacturing procedures, allowing for more flexible and efficient production of a wide range of goods.

Autonomous Robot

Robots that can function autonomously are machines that can complete tasks without direct human supervision. They have sensors, cameras, and other technology that let them move around and function in a variety of settings.

Autonomous robots can be utilized to boost productivity, flexibility, versatility and safety of production operations in the context of Industry 4.0[47]. According to [48], they can be employed, for instance, to carry out operations like material handling, assembly, and inspection, freeing up human workers to concentrate on more difficult jobs.

Augmented Reality

The term augmented reality (AR) describes the application of technology to improve or augment a user's perspective of the physical environment by superimposing digital data or images on their view of it [49]. Augmented reality can be utilized in Industry 4.0 to increase productivity, decrease errors, and improve staff training and education.

For jobs like assembly or maintenance, for instance, AR can be used to give workers real-time direction and instructions by superimposing digital instructions and diagrams onto their perspective of the work area. This can increase task efficiency and aid to cut down on errors[50].

Employees can receive virtual training and instruction through AR, giving them the opportunity to learn and practice new abilities before using them in the real world. This could enhance the training process' efficacy and safety.

Cybersecurity

Because the incorporation of cutting-edge digital technology into established manufacturing and industrial processes creates new vulnerabilities and risks, cybersecurity is a crucial concern in the context of Industry 4.0. Systems used in Industry 4.0 are frequently interconnected with the Internet of Things, making them vulnerable to viruses, hacking, and data breaches [51].

Organizations must put strong cybersecurity safeguards in place to safeguard their Industry 4.0 systems and data in order to meet these dangers. This could involve safeguards against cyberattacks like firewalls, antivirus software, and encryption in addition to protocols for secure data management and access control to stop unauthorized access to private data.

Organizations should also have a thorough cybersecurity plan in place that describes how they will manage and reduce cyber threats. This could involve conducting regular security audits, educating staff members about cybersecurity best practices, and creating incident response plans to deal with any cyber incidents.

As it helps to protect the confidentiality, integrity, and availability of crucial data and systems, effective cybersecurity is fundamental to the successful installation and operation of Industry 4.0 technologies [52].

2.1.3. Digitalization

Many manufacturing companies are pursuing industrial digitalization as a result of the current economic climate, which is characterized by globalization, uncertainty, and the pressure of competitiveness [53]. It is described as the adoption and use of these (digital) technologies in a wider range of individual, organizational, and societal contexts. It encompasses a variety of sociotechnical phenomena and processes[54].

This can entail automating procedures, gathering and analyzing data, and integrating technologies throughout an industry's whole value chain. Industrial digitalization may boost productivity, cut costs, and open up new business opportunities [55].

Furthermore, by using industrial digitalization, senior level executives can get a comprehensive and detailed insight of the business's operations, as shown in Figure 9.

Figure 9 – Digitalization [56]

Thus, as noted by Parviainen [57], digitalization is already having an impact on corporate working environments. Neglecting digitalization could put businesses in danger of falling behind in today's fiercely competitive marketplaces. The entire operating environment and internal operations of a firm may be affected by digitalization. Additionally, digitization has the power to destroy existing businesses and create new ones by altering the roles of actors in a value chain.

Identifying the effects of digitalization and its objectives for an organization can be done from three different angles [57]:

1. Internal efficiency.
2. External opportunities.
3. Disruptive change.

The first one has to do with reorganizing internal operations and enhancing productivity through digital means. The second one highlights potential new business ventures inside an already established industry. The final one indicates that digitization radically alters corporate responsibilities.

It was feasible to comprehend the significance of digital transformation and its effect on enterprises in Portugal through a study that was conducted [58]. It allowed for the recognition of the advantages of digital transformation in businesses, as well as how crucial it is and how much it affects knowledge management and organizational performance.

2.2. Lean Management

Lean Management is a key component of this theory, and it deserves top priority for a number of convincing reasons. Lean management provides a structured, tested framework for raising operational effectiveness and fostering continuous development. Lean principles offer a tactical road map for streamlining procedures, cutting waste, and improving overall quality in the context of the thesis, which addresses the opportunities and challenges faced by the cork block production business.

Lean management immediately tackles the industry's pressing need to increase cork block yields and streamline processes by placing an emphasis on doing away with non-value-added tasks and encouraging a culture of continuous improvement. The thesis uses lean approaches to pinpoint important process improvement opportunities as well as provide workable solutions to increase output and reduce waste.

It is also smoothly integrated into the larger Industry 4.0 framework, which emphasizes the use of digital technology and data-driven decision-making. The cork block production industry is better positioned to prosper in a time of increased competition and changing consumer needs because to the synergy between Lean and Industry 4.0.

2.2.1. Introduction

In the modern industrial environment, businesses seek out more means of gaining a competitive edge by raising the caliber of their services and goods while lowering their costs. Organizations across a variety of industries have adopted the Lean strategy as a result of this climate of aggressiveness and constant improvement. Therefore, for any type of firm to survive, developing a lean manufacturing system is becoming a basic capability[59].

After the Second World War, Japanese manufacturers realized they couldn't afford the enormous investments necessary to reconstruct their destroyed facilities, which is when the lean concept first appeared[60]. By concentrating on the creation of incremental changes that may enable continuous operations and production variation, Kiichiro Toyoda and Taiichi Ohno of The Toyota Motor Company stood out in this post-war context for their success and how they addressed the problems therein[61]. They did this by drawing inspiration from Ford's production method and developing their own strategy, known as the Toyota Production System - TPS .

However, the Lean philosophy only began to have relevance in the early 1990s, with Krafcik mentioning the term for the first time in his master's thesis, published by MIT in 1988[62]. But the big breakthrough for Lean came in 1990 with the publication of James P. Womack's book "The Machine that Changed the World". This became the new production system of reference, surpassing Ford's production system[63].

Lean philosophy is a multifaceted strategy that integrates several management techniques such as housekeeping, quality control, work teams, cellular manufacturing, supplier management, etc. Lean philosophy's basic tenet is that these techniques can combine to generate a streamlined, high-quality system that produces finished goods at a rate that meets customer demand with little to no waste[64].

2.2.2. Lean Principles

James P. Womack and Dan Jones' groundbreaking work claims that the Lean concept is represented and built around tenets that guarantee proper implementation [65]. These enable the detection of industrial processes, wasteful expenditures, and incompetent or inefficient operations. Consequently, the following Figure 10 lists the five principles.

Figure 10 - Lean Principles [66]

These five lean concepts, which are frequently linked to the Toyota Production System (TPS), offer a framework for businesses to optimize their processes, cut waste, improve quality, and provide consumers with more value.

2.2.3. Kaizen

Although it is not part of the Lean concept, kaizen and the Lean philosophy are directly related, one being an inherent part of the application of the other. That's why it's important to address the Kaizen term.
The Kaizen principle, which seeks harmony through constant development, is founded on old Japanese tradition and philosophy. Modern versions of it are used to streamline and enhance commercial operations as well as personal growth. The true meaning of this expression taken from the Taoist and Buddhist tradition, focused on improvement for the entire society, and still present in Japan to this day—this being the most important concept in Japanese management—is that improvement in Kaizen should not be seen in isolation but rather in a broader context [67,68].

Kaizen is a Japanese term that refers to the practice of continuous improvement. It is a philosophy that emphasizes the importance of small, incremental changes and the involvement of all employees in the improvement process. Masaaki Imai, the father of Kaizen strategy, claims that it is a methodology that, when used properly, minimizes waste in company operations, enables individuals to quickly adjust to challenging circumstances, and removes unneeded demanding effort, both mentally and physically [68].

The principles of kaizen can be applied in any organization or industry, and can be used to improve processes, products, and services. The goal of kaizen is to identify and eliminate waste and inefficiencies in order to increase efficiency, reduce costs, and improve customer satisfaction.

Kaizen involves a continuous cycle of planning, implementing, and evaluating small changes in order to achieve incremental improvements over time[69]. This approach focuses on involving all employees in the improvement process and encouraging them to identify and suggest improvements. Kaizen also emphasizes the importance of continuous learning and the adoption of a long-term perspective on improvement [70].

Kaizen is frequently given as a collection of principles in the form of rules [68]:

- Discard conventional fixed ideas.
- Think of how to do it, not why it cannot be done.
- Do not make excuses. Start by questioning current practices.
- Do not seek perfection. Do it right away even if it will only achieve 50% of the target.
- If you make a mistake, correct it right away.
- Throw wisdom at a problem, not Money.
- Ask 'WHY?" five times and seek root causes.
- Seek the wisdom of ten people rather than the knowledge of one.

Don't ask workers to leave their brains at the factory gate.

2.2.4. Lean Tools

Manufacturers must gather, manage, and analyze production data in order to make wise decisions about their business. Production data, however, is frequently prone to mistakes, inconsistencies, and inaccuracies, which can have a detrimental effect on company outcomes. Production data quality may be improved using lean tools and practices, which can boost operational effectiveness, cut costs, and boost productivity.

As they reflect the application of the Lean philosophy itself, lean tools play a crucial role in the lean concept. They are used to cut down on waste, boost production, and encourage innovation. Consequently, strategies, processes, and tools must be used in order to enable the adoption of the Lean ideology in a business[71,72]. This chapter will examine five lean tools that may be used to enhance the quality of production data.

Value Stream Mapping

The Value Stream Mapping (VSM) is used to find and get rid of waste in manufacturing processes. It is predicated on the notion of figuring out which phases in a process contribute value and getting rid of the rest. The tool was created as a component of the Lean Management, and numerous businesses all around the world have subsequently embraced it [73,74].

VSM is an effective method for examining data and material flow in a certain process. The whole value stream, from the raw ingredients to the completed product, is mapped out using it. The mapping procedure entails listing every step in the process along with how long it takes to finish each one. The wasteful areas are then found, such as surplus inventory or unneeded waiting periods, using this information[75].

One of the main advantages of VSM, example in Figure 11, is that it aids businesses in locating and removing production-related bottlenecks[76]. When there is a lack of resources, such as staff or equipment, the manufacturing process is delayed, creating bottlenecks. Companies may take action to remove these bottlenecks and enhance the flow of materials and information through the manufacturing process by identifying them through the mapping process[77].

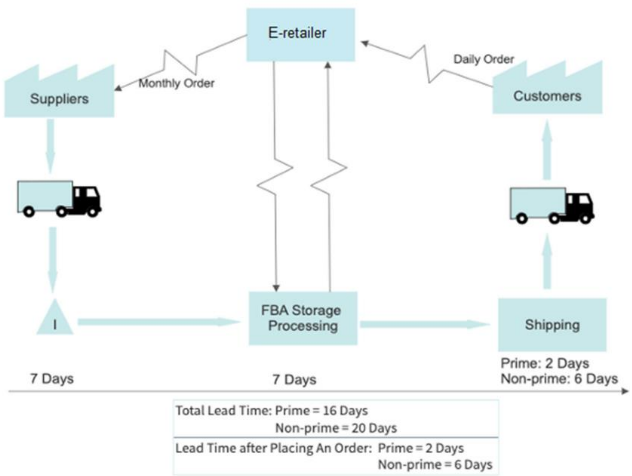


Figure 11 – Example VSM [78]

5S

The 5S lean tool is a tool that can help organizations to improve efficiency, reduce waste, and promote a culture of continuous improvement in their operations.

The 5S stand for Sort, Set in Order, Shine, Standardize, and Sustain [79], Figure 12. In the Sort step, the organization removes any unnecessary items from the work area, leaving only the essential tools and materials. In Set in Order, the remaining items are organized in a logical and efficient manner, making it easier for employees to find what they need when they need it. The Shine step involves cleaning and maintaining the work area, which not only improves the appearance but also helps to identify any maintenance issues that may be affecting efficiency[80].

The Standardize step involves creating standard operating procedures and work instructions that ensure consistency and quality in the work that is performed. This step also helps to identify opportunities for improvement and encourages employees to contribute their ideas and suggestions for better ways of working. Finally, the Sustain step involves creating a culture of continuous improvement by regularly reviewing and refining the processes and procedures and ensuring that they are consistently followed[81].

The 5S can be applied to a wide range of industries and processes, from manufacturing and production to healthcare and services. By promoting efficiency, reducing waste, and creating a culture of continuous improvement, the 5S can help organizations to improve their operations and gain a competitive advantage[79].

Figure 12 - 5s [82]

There is numerous research that supports the use of 5S. For instance, the use of 5S was found to be crucial in research done in a metalworking industry [83], with outcomes including improved workstation safety, increased production, and significantly less waste. It also demonstrated a willingness to alter the company's organizational structure.

Visual Management

Visual Management is a lean tool that uses visual cues to help people understand and manage processes more effectively. It involves using visual aids such as signs, charts, graphs, and other visual tools to communicate valuable information about the process, its performance, and its status[84].

The main components of Visual Management are[85]:

1. Visual Controls - These are physical or electronic displays that provide real-time information about the process. Examples of visual controls include status boards, work instructions, and display screens that show data about the process.
2. Standardization -Focuses on the process of creating consistent and repeatable procedures for tasks in the production process. This includes standardizing work instructions, tools, and equipment to ensure that everyone follows the same process.
3. 5S - Represents a lean tool that involves organizing the work environment to optimize efficiency and minimize waste. It includes five steps: Sort, Set in Order, Shine, Standardize, and Sustain.
4. Andon - This is a visual signaling system used to indicate the status of a process or machine. It can be used to alert workers to a problem or to indicate that a task is complete.

By using visual management, organizations can make it easier for employees to understand the process and monitor its performance. Visual tools can be used to communicate key information about the process, such as targets, goals, and metrics, making it easier for employees to identify problems and take corrective action when needed. Additionally, visual management can be used to standardize work procedures, reduce variability, and minimize errors[85,86].

Visual management, Figure 13, is especially useful in production environments, where it is essential to quickly identify and resolve issues that could lead to production delays or product defects. By using visual management tools, organizations can improve their efficiency, reduce waste, and improve overall quality, resulting in greater customer satisfaction and a more competitive position in the marketplace.

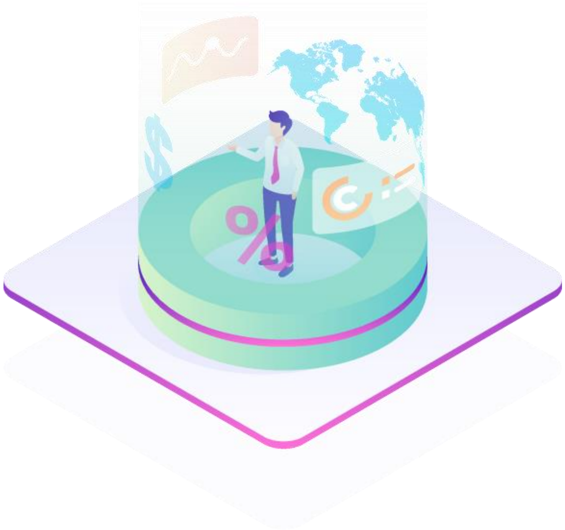


Figure 13 - Visual Management [87]

TPM

Total Productive Maintenance (TPM) is a lean tool that focuses on improving the efficiency and effectiveness of production equipment by involving all employees in the maintenance process. The goal of TPM is to maximize the productivity of the equipment, reduce downtime, and increase the overall effectiveness of the production process[88].

The TPM methodology has several components, as shown in Figure14, including[89]:

- Autonomous Maintenance - In this component, operators are trained to perform routine maintenance tasks on the equipment, such as cleaning and lubrication. This helps to identify issues early on and prevent breakdowns and other equipment failures.

- Planned Maintenance - In this component, maintenance activities are planned and scheduled to minimize the impact on production. This includes regular maintenance activities, such as inspections and replacements, as well as predictive maintenance, which uses data analysis to predict equipment failures and schedule maintenance before a breakdown occurs.

- Quality Maintenance - In this component, the focus is on preventing defects and ensuring that the equipment is operating within established quality parameters. This involves monitoring key performance indicators (KPIs) and implementing corrective actions as needed to maintain quality standards.

- Education and Training - In this component, employees are trained in the proper use and maintenance of equipment, as well as in continuous improvement methodologies. This helps to ensure that everyone is working together to identify and solve problems, and to continuously improve the production process.

- Safety, Health and Environment - In this component, the focus is on ensuring that the equipment is safe to use, and that the production process is environmentally friendly. This involves monitoring safety and environmental performance, identifying areas for improvement, and implementing corrective actions to minimize risks and reduce waste.

Overall, TPM can help organizations to improve the effectiveness and efficiency of their production processes by involving all employees in the maintenance process and creating a culture of continuous improvement. By reducing downtime, preventing defects, and ensuring that equipment is operating at peak performance, organizations can improve their productivity, reduce costs, and gain a competitive advantage in the marketplace[90].

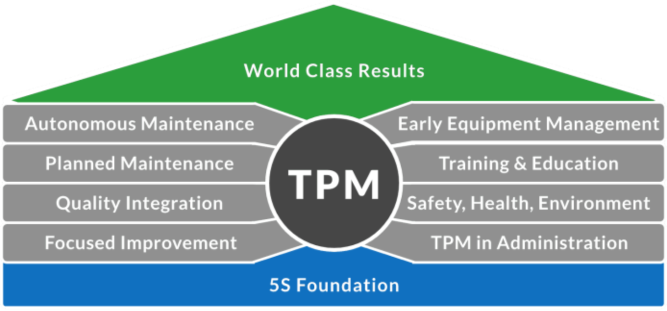


Figure 14 – TPM [91]

SMED

A lean manufacturing technique called single-minute exchange of die (SMED), Figure 15, seeks to reduce the amount of time needed for setups or changeovers in production processes. Reduce downtime associated with switching from one product or process to another is the main goal of SMED. Although it is not always possible to shift over in exactly one minute, the term "Single-Minute" refers to a significant reduction in changeover times, frequently from hours to minutes. Internal setup operations and external setup activities are separated by SMED. External setup chores can be finished while the machine is running, however internal setup tasks can only be finished when the machine is stopped. SMED seeks to hasten changeovers, increase operational flexibility, and boost overall production effectiveness by outsourcing internal setup duties.

SMED has a broad range of real-world applications in several manufacturing areas. The decrease in downtime, which allows for more production capacity and flexibility, is one of its main advantages. Manufacturers may adapt more quickly to changes in client demand, switch between different product lines more effectively, and ultimately increase their competitiveness in a dynamic market by expediting changeover operations. Through reduced downtime, fewer labor demands, and the opportunity for smaller batch sizes, SMED also results in cost benefits by lowering waste and inventory expenses.

Additionally, SMED encourages worker empowerment and involvement. Employees get more interested in enhancing operational efficiency as they actively participate in the process of identifying and removing non-value-added operations. This increased involvement develops a culture of continual development within the company and boosts morale[92–96].

In a study carried out by Silva [97], when applying the SMED methodology to cutting lines, it was possible to reduce the setup time and use fewer human resources for it.

Figure 15 – SMED [98]

Gemba walks

The site where work is actually being done, such as the factory floor, shop floor, or any other operational area, is referred to as "the real place" or *Gemba*, in Japanese. The *Gemba* walk is travelling to the Gemba, looking at the labor procedures, and interacting with the workers there[99].

Gaining a thorough grasp of the present condition of operations, identifying waste or inefficiencies, and fostering a culture of continuous improvement are the goals of the *Gemba* walk. It enables managers and leaders to keep a close eye on employees' job activities, ask questions to learn more, and compile information before making judgments based on current knowledge.

The *Gemba* walk stimulates open communication, allows workers to express their views and comments, and develops a feeling of ownership and accountability by actively engaging with workers on the shop floor. It assists in locating bottlenecks, flaws, security risks, and other problems that could obstruct output or quality.

The objectives of lean thinking, which include waste reduction, process enhancement, and customer value creation, are in line with the *Ge*mba walk. It gives businesses the ability to spot possibilities for process standardization, innovation, and optimization, which enhances overall performance [100–103].

Daily Kaizen

Daily Kaizen, commonly referred to as daily continuous improvement, is a lean management and Kaizen philosophy practice. It entails daily minor, incremental changes to systems and work processes. The purpose of Daily Kaizen is to instill a culture of continuous improvement and to provide every employee the opportunity to enhance the business [76,104].

Instead of making radical changes, Daily Kaizen emphasizes constantly minor advancements. It encourages staff members to find little adjustments they can make that will improve their workflow, output, quality, and safety.

Employees are the ones who are most familiar with work procedures and are frequently in a position to identify opportunities for improvement, according to the daily kaizen philosophy. All staff members are encouraged to take part in daily improvement activities and offer their suggestions on how to make their jobs simpler, quicker, or more effective.

Daily Kaizen encourages an attitude for fixing problems. It encourages staff members to actively look for issues or inefficiencies in their workplaces, investigate the causes, and put corrective measures in place. This iterative method to problem-solving aids in creating a culture of continual learning and progress.

The cornerstone for improvement, according to Daily Kaizen, is standardization work procedures. Organizations may build a baseline for finding deviations, inefficiencies, and possibilities for improvement by creating standardized work routines. Employees are encouraged to spot deviations from the norm and suggest changes to bring workflows back in line with standards through the daily kaizen initiative.

Daily Kaizen frequently uses visual management to make improvement efforts and progress apparent to everyone inside the business. To convey improvement objectives, monitor progress, and recognize accomplishments, visual tools including Kanban boards, improvement suggestion boards, and performance measures are employed.

Leaders and managers must actively encourage and participate in daily kaizen. Leaders are essential in fostering an improvement-friendly workplace, offering tools and training, removing barriers, and recognizing and rewarding staff members who make improvements.

3. PROCESS AND PROBLEM ANALYSIS

The goal of this chapter is to put the industrial unit where the project or internship took place and the areas that include it into context. In addition, the flow of materials and the associated processes will be characterized and examined. The action plan will then be outlined together with a description of the original status of the region and the issues that were discovered.

3.1. Characterization of the Production Process

As presented in chapter 1, the corporation is divided into five industrial divisions, each of which has a customer-supplier connection inside the organization. As a result, from the time raw materials arrive until the final product phase, there is a very high flow of materials.

Composite cork materials made with other materials, such as rubber, EVA, TRW, and foams, are the responsibility of the industrial area where the project is located.

The two processes that make up the region where the internship is located, the stage of cork and rubber block and cylinder agglomeration and the area of their transformation into rolls and plates, with more attention paid to this, will be covered in the following subchapters.

The material flow that creates the products in the slab transformation area is displayed in Figure 16 for better comprehension.

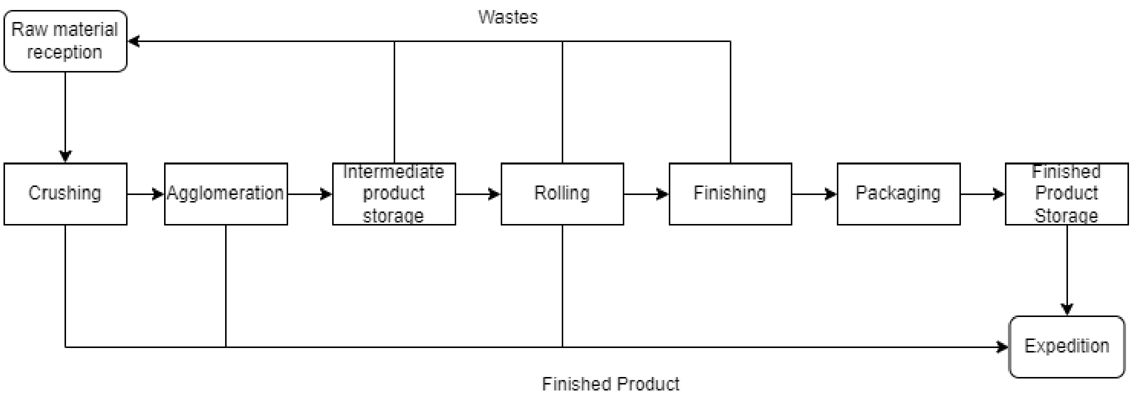


Figure 16 - IU 3 Process Flow

It should be noted that the process of agglomerating blocks (CR1 line) and turning them into the slabs the customer requested was the main focus of this project. The area of operation is in rubber and cork composite blocks, so emphasis will be given to this process and the part of the industrial unit that focuses on the agglomeration of cylinders and their subsequent transformation will be left aside.

3.1.1. Block Agglomeration Process

The Industrial Unit's Agglomeration area, which gets cork granules from another industrial unit area and the rest of the ingredients from suppliers, which are held in the Raw Materials Warehouse, is where blocks are first made. Cork composite blocks are created later when these components are mixed in the agglomeration process.

In figure 17, we can see the blocks that are extracted from the agglomeration zone.

Figure 17 - Cork composite blocks

In this chapter, we'll discuss how the process of agglomerating blocks works and how it's defined. Initially, a process diagram was created to clarify and streamline the production process, represented in Figure 18. This outlines each step in the process that results in the manufacturing of blocks, including operations, control, storage, and transportation.

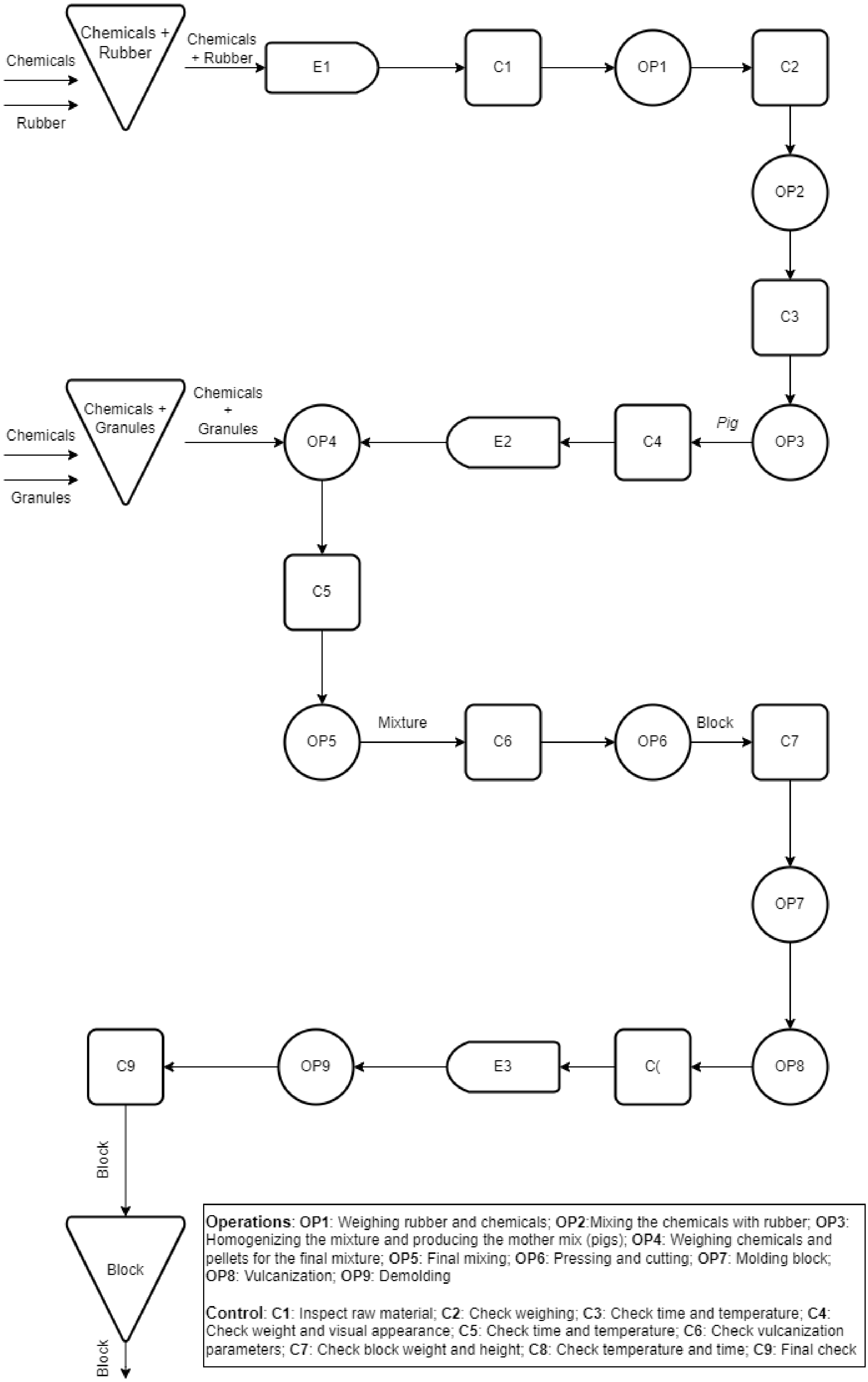


Figure 18 - Process Diagram

It is important to keep in mind that the manufacturing line (CR1 Line) is placed vertically along a steel structure with four stories owing to a shortage of available space. In essence, the following is how the activity along this production line is distributed:

Via ducts the granulate from another business industrial area is initially carried to the cyclones, Figure 19, in charge of extracting, separating, regulating, and dosing the cork granulate.

Figure 19 - Cyclones

Then, the granules from the industrial grinding section are moved into and kept in mini silos as we can see in Figure 20 and each of which is designed to hold a certain kind of granule.

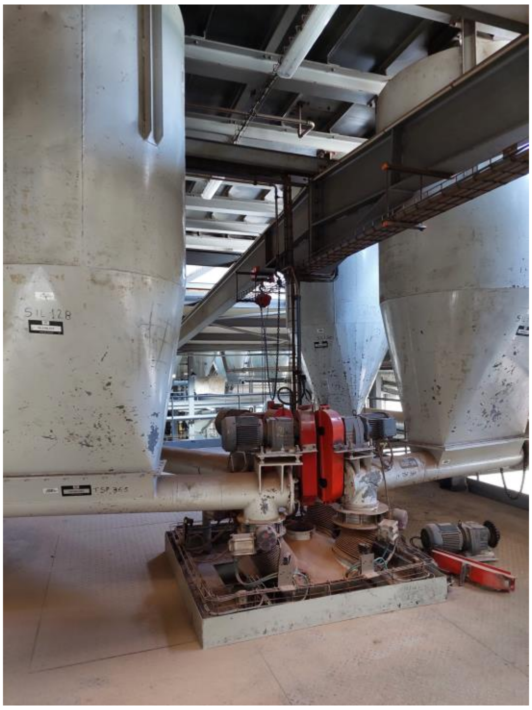


Figure 20 - Mini Silos

A scale, above in Figure 21, that accepts the granules from the silos may be seen on the third floor. The corresponding grains are placed inside the Banbury mixing chamber after being given the appropriate weight. It should be noted that the CR1 line's chemical products are kept on the same level.

Figure 21 - Scale

The chemical scales are on the floor below. Here, the weighing is carried out automatically and with the use of lockers, Figure 22. The producer is then instructed to continue with manufacturing after combining them with the mother mix (*pigs*). The mixing procedure starts when these ingredients are introduced to the Banbury.

Figure 22 – Chemical scales and lockers

The mixture is sent to the open homogenizing mixer, as showed in Figure 23, after the formula temperature and mixing duration have been attained. This is located on the first level and is made up of two cylinders that chill and uniformize the mixture by rotating in opposing directions. Here, a rheometer-assisted study is conducted to look for any quality issues.

Figure 23 - Open Homogenizing Mixer

The mixture is then moved to the guillotine on a conveyor while already in a band configuration. In order to ensure higher success in the stacking phase, presented in Figure 24, the operators examine any surface flaws throughout this procedure. The web is divided into sheets at the guillotine based on the required item and size. After that, the sheets are piled to the necessary weight for the particular manufacturing order.

Figure 24 - Stacking phase

The finished sheet layer is then brought to the cutting press table, shown in Figure 25, where the cutter and presser foot descended and cut and press the sheet to the required dimensions. This results in the block being obtained, which is then measured and weighed. The waste generated by this procedure is fed back into the open homogenizing mixer.

Figure 25 - Cutting Press Table and Process

The next process involves transporting the block from the cutting press to the mold press, as visualized in Figure 26, with the help of a lift table and the operator. Here, the block is inserted into the mold, where it is then joined by the mold cover exerting slight compression on the material. Depending on the mold, the dowels are inserted and are given the order to advance to the greenhouse entry area.

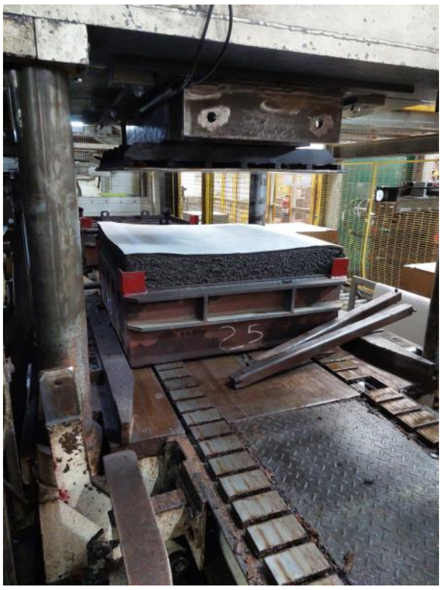


Figure 26 - Mold Press Table and Process

The block is positioned in the chamber exit zone after vulcanization. All vulcanized blocks are demolded (taken from the molds) and put on a pallet after being correctly labeled with the production date (batch), reference, weight, and mold employed. Next we can see the described in Figure 27.

Figure 27 - Finished Blocks from the Agglomeration Process

3.1.2. Slab Transformation Process

In general, the transformation Lamination area converts blocks (from the agglomeration area) into slabs with different thicknesses that are similar in size in proportion to the base. It should be emphasized that this method adheres to the make-to-order concept in that rolling procedures are only carried out when orders are received, and the appropriate manufacturing order is opened. The process type is a job shop in this sense.

The lamination of blocks into slabs is, in itself, a very challenging area that involves a lot of skill and attention from the laminators. It is important then to know better how the process works and its characteristics for a better understanding of the project itself.

Four major steps of a certain procedure will be detailed in this chapter.

1. Preheating in an oven in accordance with the laminate block recommendations

The cork blocks need to go through a preheating procedure in a greenhouse, presented in Figure 28, before the actual laminating. This procedure is crucial to make the blocks less humid at the moment and more flexible, which will make lamination easier. Depending on the references of the blocks that will be laminated, different preheating times and temperatures are used.

Figure 28 - Preheating Kiln

The blocks are then placed at the rolling table's entrance, Figure 29. This is where a "block grabber"—a device for situating blocks—can be used to make the process of placing them on the table easier.

Figure 29 - Pre-lamination

2. Adding the blocks to the rolling table:

The cork blocks are carefully set on the laminating table after preheating. To guarantee consistent lamination, it is crucial to ensure that the blocks are level and oriented correctly. These are positioned such that cutting is optimum and wear is reduced compared to if the blocks were flush with the table all the way around. In this manner, the blocks are placed with a 10° inclination with regard to the plane's side edge orientation.

The process described can be seen in figure 30.

Figure 30 - Lamination Process

3. Make the block bases clean:

The bases of the cork blocks need to be meticulously cleaned before you begin laminating. By doing this, it is possible to guarantee the uniformity and cleanliness of the laminated slabs. This is accomplished by laminating the upper base at a 2mm thickness until the molding paper has been totally or nearly completely removed from the surface and the base is uniform. The process is then repeated with the new base of the same block, by turning it around. The block is measured for height and its yield is taken for rolling at the conclusion of this procedure. Finally, the operator must clean the work area with compressed air and proceed to rolling.

In Figure 31 we can see the stages of the processes presented.

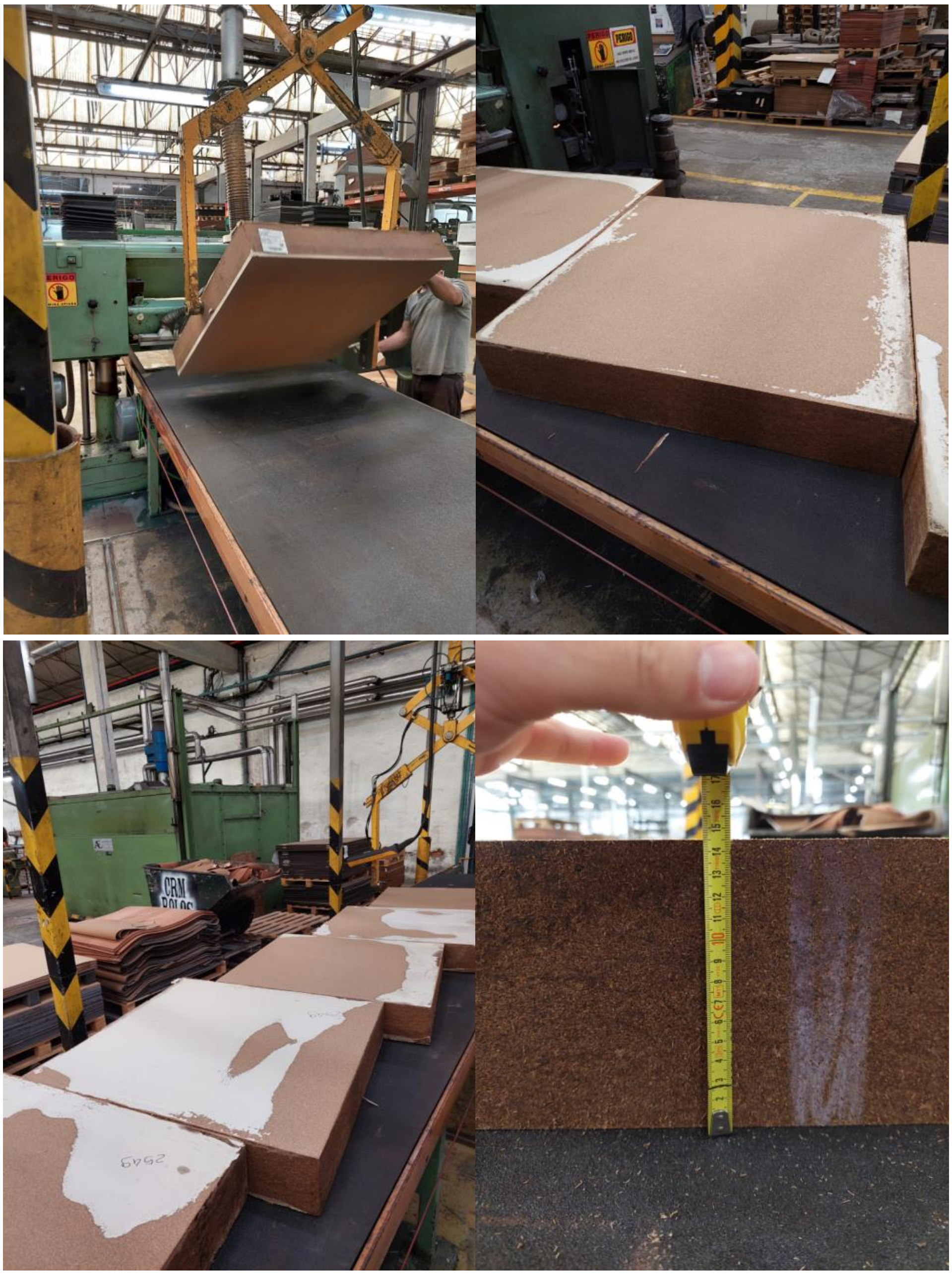


Figure 31 - Cleaning, tunring and measuring of blocks

4. Start laminating to the preferred thickness in accordance with the MO:

The laminating procedure is finally initiated. A laminating machine is used to press the cork boards together to create a single laminated board. The requirements of the customer's production order (OF) are used to alter the laminated plate's thickness. An example can be seen in Figure 32.

Figure 32 - Laminated sheets

In conclusion, according to the OF, the procedure for turning cork blocks into slabs by lamination include preheating the blocks in an oven, setting them on the lamination table, cleaning the bases of the blocks, and laminating them to the necessary thickness. This procedure is essential for producing high-quality cork slabs that are appropriate for a wide range of uses.

The plates are finally arranged and grouped in the most efficient manner for later packing, just as Figure 33 suggests.

Figure 33 - Placing of final product

3.2. Initial Situation Presentation

Upon entering the organization, it became necessary to enhance and retrieve production-related data that had either become stale or had been improperly exploited. These data could be used to assist top management and enable the development of indicators for a better comprehension and control of the region of cork block transformation.

In keeping with this theme, it was made evident that the area of laminating blocks in cork slabs did not generate the anticipated amount of revenue when the financial results were shown per area of work (Report in Index). In other words, the area's gross margin fell short of the benchmark set by the business' engineering department, reported in the P&L (Profits and Losses) report. A research was then undertaken in order to address this data reported to management control, and it was found that the consumptions made in the block transformation area were significantly higher than what was anticipated in the system for the manufacturing of slabs. In this regard, a 2022 study was undertaken to determine the potential effects of variations in consumption on the region's gross margin. Thus, we were able to obtain the information from the following Figure 34 by comparing projected and actual consumption for the months of 2022:

Month_Year	Total Produced (€)	Total Theoretical Consumption (€)	Total Actual Consumption (€)	Consumption Deviation (€)	Consumption Deviation (%)	Theoretical GM (€)	Real GM(€)
jan/22	229 491,31 €	217 283,68 €	228 076,72 €	10 793,04 €	4,73%	12 207,63 €	1 414,59 €
fev/22	297 159,45 €	282 489,24 €	292 255,76 €	9 766,52 €	3,34%	14 670,21 €	4 903,69 €
mar/22	309 826,54 €	294 684,33 €	306 585,89 €	11 901,56 €	3,88%	15 142,21 €	3 240,65 €
abr/22	227 563,03 €	215 813,66 €	223 795,53 €	7 981,87 €	3,57%	11 749,37 €	3 767,50 €
mai/22	269 128,94 €	250 500,35 €	264 210,28 €	13 709,93 €	5,19%	18 628,59 €	4 918,66 €
jun/22	233 135,84 €	224 316,21 €	239 614,27 €	15 298,06 €	6,38%	8 819,63 €	-6 478,43 €
jul/22	262 140,56 €	245 735,92 €	250 556,42 €	4 820,50 €	1,92%	16 404,64 €	11 584,14 €
set/22	248 601,13 €	229 641,68 €	234 725,60 €	5 083,92 €	2,17%	18 959,45 €	13 875,53 €
out/22	254 301,08 €	235 897,36 €	238 636,30 €	2 738,94 €	1,15%	18 403,72 €	15 664,78 €
nov/22	283 068,83 €	263 442,46 €	274 642,30 €	11 199,84 €	4,08%	19 626,37 €	8 426,53 €

Figure 34 - Theoretical vs real financial results

As we can see, consumption fluctuations might be rather large and affect the region's monthly gross margin. The month of June 2022 marks the maximum point of this departure, when the percentage of deviation reaches 6.38%, which translates to a monetary deviation of 15298.06 €. Since August and December are months of low productivity in the organization and are therefore regarded as outliers, they were not taken into account for this study. A chart contrasting the theoretical and real gross margin was created as analytical support, as presented in Figure 35.

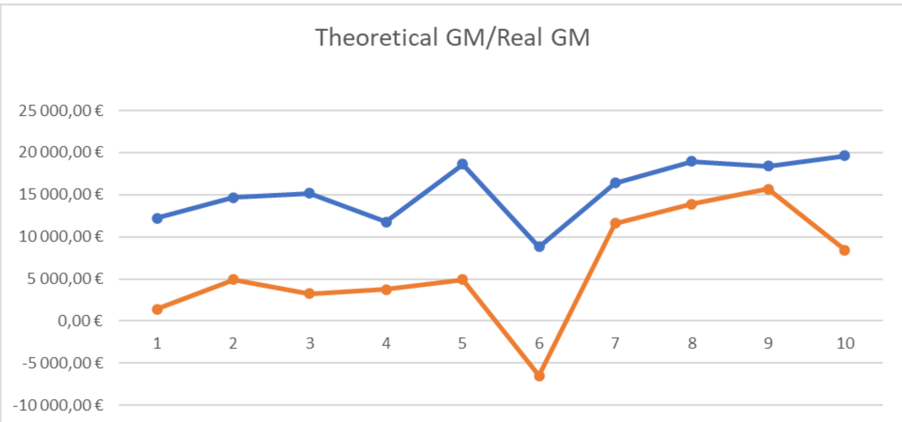


Figure 35 - Theoretical GM/ Real GM

The yield (block height at the start of rolling process), which is below standard, and issues with quality and quantity of rejects in the region are the primary causes of this.

As a result, a project was developed with the intention of solving this issue, the blocks yield. Following this yield-related theme, the anticipated block height prior to the removal of slabs from the block is shown below.

Figure 36 - Ideal Process

As we can see in Figure 36, the blocks have heights between 160 mm and 170 mm as they leave the agglomeration zone. As they reach the processing zone and undergo cleaning to equalize the bases of the blocks for the best slab collection possible, it is anticipated that these blocks will have a height/yield of 150 mm. The average yield was 145 mm, which showed that the area was already beginning to be lost even before the rolling process, according to an examination of the variations in the area and after actual measurements. Consequently, it was required to raise this value to the level of the norm.

In order to increase the gross margin, the following are the project's primary areas of focus: boosting the block yield and using unused data can enhance organizational decision-making and information flow as represented in Figure 37.

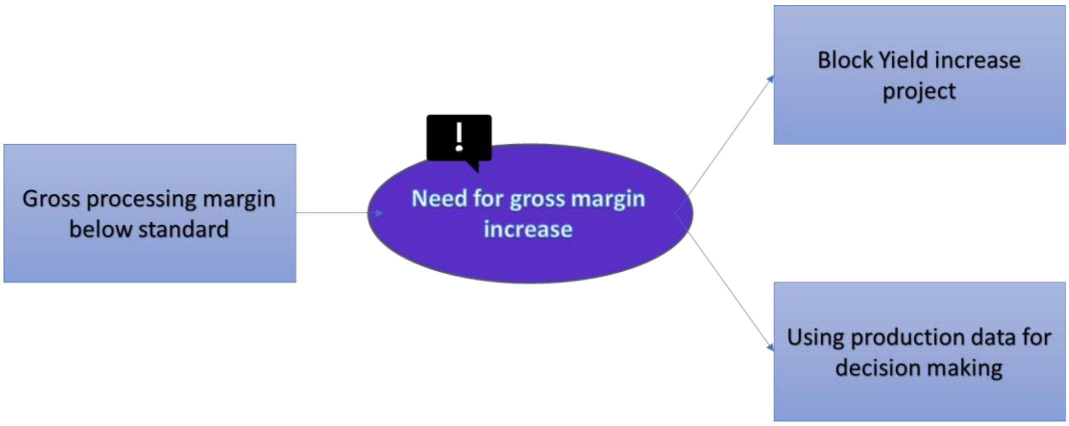


Figure 37 - Project's aim

3.3. Problem Characterization

Even if the losses are felt in the slab processing area, the yield issue in the blocks affects them from the time of their conception, agglomeration, and slab manufacture. In Figure 38 we can see these 2 areas of work. Thus, the processes of agglomeration, block demolding, slab rolling, and board rolling were examined for the approach of issue discovery.

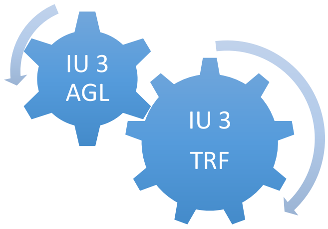


Figure 38 - Areas of work

Gemba walks were thus carried out for this research in order to comprehend the situation on the shop floor in the two sections. There was then space for the establishment of weekly meetings to bring together the entire industrial unit's team, including the maintenance team, process engineering, controllers, supervisors, and industrial director—something that had not previously occurred—and attempt to identify and categorize the issues that were inherent in the problems. These meetings were essential and often held during the organization's months in existence. The comments from the shop floor operators, who, with their expertise, supplied useful insights that were distinct from those presented by other project participants, was another action done to strengthen this preliminary study.

In a nutshell 36 issues were found that might, via yield, have an impact on the work center and cost of the slab processing area. These issues were then separated into three categories: area, agglomeration, and transformation, with 18 issues falling under the first category and the rest 18 under the rolling process. Having stated so, we have already recognized each of them in Table 2 and 3.

Table 2 - AGL Problems

Nº	Problem
1	Misinformation about the density of the granulates in use
2	Blocks with regular surface, but sub-standard height
3	Demolding Difficulties
4	Limited knowledge by the Workers about Quality problems on the line
5	Damage to the sides in the press cutting process
6	Warped Molds and Covers
7	Blocks with missing height in the sheet position process
8	Lack of mold cleaning
9	Mismatched information on block weights
10	Absence of rheometer tests
11	Lack of uniformity in the working thickness in the Mixer for certain references
12	Amount of resin applied in the mix is a variable not controlled in the process
13	Damage to the sides of the blocks due to "block grabbing"
14	Passing the mix through the Mixer causes a change in density
15	Problem with dowel fit in automatic molds
16	Work rate variation causes differences in block heights
17	Appearance of burrs on blocks and slabs
18	Error in formulas

Table 3 - TRF Problems

Nº	Problem
1	Defective printing
2	Worn sandpaper
3	Inaccuracy of the chargebacks made and quantity produced
4	Crooked slabs and blocks
5	Non-existence of cleaning standards in the blocks during rolling
6	Curved blocks from the block kiln
7	Indefinition in procedural and planning management
8	Worn out rolling mill planes
9	Different yields when cleaning on the sander
10	Rounding errors and lack of validation
11	Rolling thickness different from packing thickness
12	Different yields for different references
13	Collage problems
14	Irregularities in rolling thickness
15	Inconsistent part measurement
16	Operators may not know the target yield of rolling mills
17	Gluing frames out of specification
18	No validation of table-to-plane distance

Once the problem-solving phase was complete, the Ishikawa Diagram, represented in Figure 39, and the Lean concept were used to categorize and separate issues during the problem-segregation and -characterization phase. The following categories apply to these "6M's":

- Manpower;
- Materials;
- Machines;
- Methods;
- Measurements;
- Mother Nature;

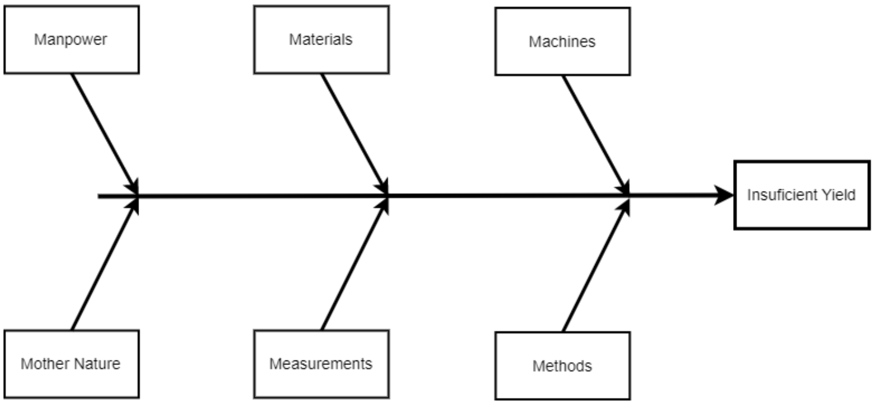


Figure 39 - Ishikawa Diagram

As a consequence, the study and the table below show that the majority of the issues were connected to the root methods/processes, as shown in Figure 40. The team was able to determine from this analysis which field has the biggest influence on the effectiveness of the blocks and, on the other hand, to prioritize resolving process-related issues. It has also been noted that tools and machinery tend to cause quite a few problems.

Type	nº
Methods/Process	19
Machines	8
Manpower	5
Measurements	3
Materials	1
Mother Nature	0
	36

Figure 40 - Nº of problems per type

Then there was space for work-area segregation, agglomeration (AGL), and transformation (TRF). With this action, we realized that the most incident type of problem is independent of the work area and that the actions would have greater representation on the process and maintenance team, together with supervision. This kind of research and analysis focuses on how data may be used to further the project's second goal, which is to enhance decision-making.

The following Figure 41 applies the study carried out

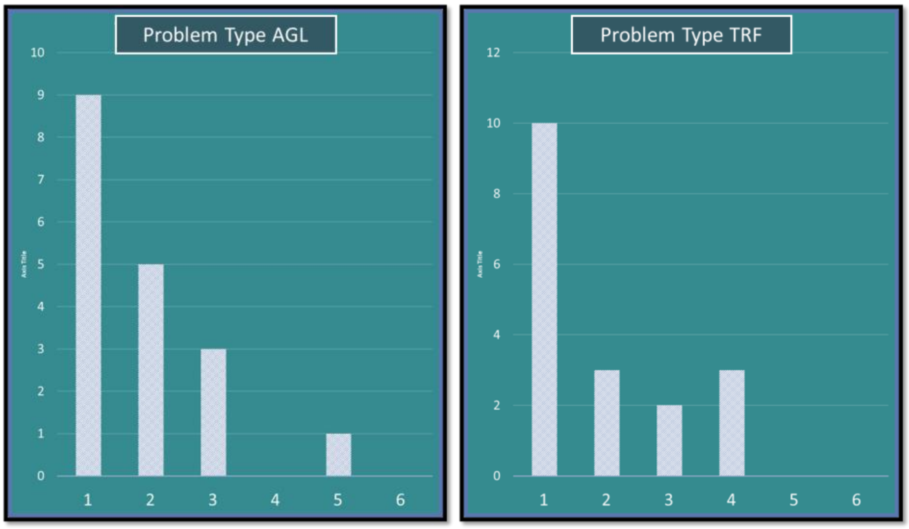


Figure 41 - Nº of problems/type in both areas (AGL and TRF)

Following this, there was a phase of planning and executing improvement measures in the areas of block yields and using underused data to enhance information flow and decision making, which we will examine in the following chapter.

4. IMPLEMENTS, RESULTS AND ANALYSIS

This chapter will outline the action plan and all related stages involved in carrying out the project. We will discuss the development of an action plan in the first stage of the block yield and information flow enhancement project in order to better manage priorities, tasks, and concentrating on the factors that lead to the planning of these activities. The acts that had the greatest influence on the project will then be discussed in separate sub-chapters, and the impact they had on the industrial area will be confirmed using measured and validated outcomes.

4.1. Yield Improvement Project

A PDCA was conducted to assist the block yield project and the team participating in the project, the entire team at IU 3, in order to manage the actions more efficiently, to concentrate on the causes, to have better control over the project, and to manage priorities efficiently. Plan-Do-Check-Act, or PDCA, is a methodical and iterative four-step management approach used for problem-solving and continuous development. PDCA, Figure 42, offers a disciplined method for managing projects, ensuring that they are carefully planned, successfully carried out, and continually improved. Including PDCA in a project proposal has a number of important advantages. An initial action plan of six months was thought of for this and began at the end of September.

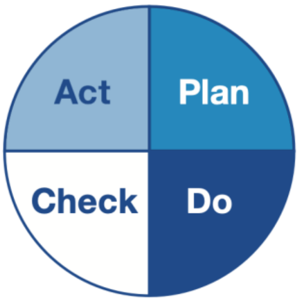


Figure 42 - PDCA

For this, 42 improvement actions were counted in total divided by the 36 problems previously identified and segregated in order to be allocated in the best way to the team members, according to the causes of the problems, it´s level of priority and their effects, something that was also fundamental for a better understanding of the problems. The timing of each of these operations was scheduled such that it would not conflict with any other planned actions and that there would be no unjustified delays that may compromise the project's objectives.

Microsoft Planner, Figure 43, which is frequently used in project management, was utilized to ensure that all participants were aware of this action plan and that it was carried out as effectively as possible. It was feasible for each member to carefully track the project thanks to this and a project consultation dashboard made in Power BI, which we will discuss later in relation to enhancing the flow of information in the company.

Figure 43 - Microsoft Planner

At the end of the six-month action plan, there were 30 completed actions and 12 that were still being implemented and finished, either because they were continuous in nature or because their original completion dates had to be revised due to their complexity and interference from outside the organization. As a result, 71% of the project was completed by the end of the allocated time.

The four activities that had a bigger influence on the project and, in a manner, fit better with the topic of the project will then be discussed in the sub-chapters that are provided. They are mold recovery, information flow improvements, training and awareness of rolling process methods, and the development of a deviation control tool.

4.1.1. Training and awareness of rolling process methods

Training and understanding of the processes in the rolling process were the first improvement action to be handled with a major impact on the project. Since there were practices, techniques, and activities that had never been standardized and normalized, the intention is to document some of the shop floor operations using this. These, in a sense, were transmitted among the operators in an unstructured and incoherent manner and required intervention. The necessity to lessen the rejection recorded in IU 3's processing region, which is responsible for many of the exacerbated discrepancies in consumption, is another aspect that prompted this improvement activity. Finally, the goal of this improvement initiative was to inform and increase awareness of the current problem with gross margin and block yield among operators and stakeholders in the agglomeration and transformation process, improving the flow of information within the industrial area.

To match the goals of the improvement plan, three activities have been implemented for the previously mentioned situation.

The first, as previously mentioned, was the standardization of certain procedures in the plate rolling process and the inclusion of operators in the scope of the project. For this, OPL's were created, in order to standardize some procedures such as cleaning, how to perform reversals, and fine-tuning of planes for rolling. To do this, we went to the rolling mill operators with the greatest expertise and those who had worked for the firm for a longer period of time, and we attempted to write down their guidelines for each of these tasks on paper before sending them to the workstations and Kaizen board located nearby the work centers. The supervisors and team leaders, on the other hand, carried out training and awareness activities to inform the operators of the yield objective and the gross margin problem in order to involve the entire area and to improve the sense of alertness and reporting to those involved in the transformation process.

Figure 44 - Standardization

The establishment of a daily meeting with the supervisor, process engineer, quality technician, and controller to discuss the rejects from the previous day on the processing line was another activity that resulted from this improvement action. Large differences in the summaries of the OFs prompted the need for this conference, which allowed for a case-by-case analysis to determine the causes and reasons behind these rejections. As a result, the nonconforming slabs were daily separated by shift and put on pallets next to the Kaizen board to be examined the following day. By taking this move, we want to give the non-conforming slabs a second chance and explain why to the operators, warning them of any possible weaknesses in the procedure. To benefit from this, cutting activities were performed to remove rejection sources and, when feasible, remit the plate to alternative dimensions. Sanding actions were also performed with the same goals, reducing slab’s thickness.

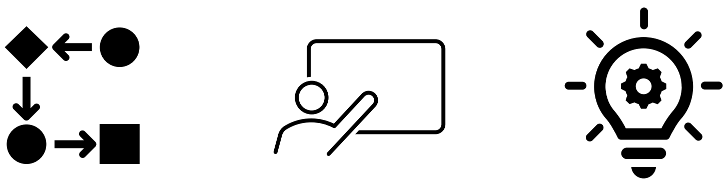


Figure 45 - Daily Meeting

Finally, there was room for the collection of these discovered rejections and their transportation to the IU 3 team's alignment meeting. Then, it is the supervisor in charge of the agglomeration's responsibility to deliver them to his region and show the operators the rejections. The operators learn considerably more about the issues that, although being felt in the transformation area, are a product of both current processes and should be followed in this way thanks to this continuous improvement routine. Thus, the fight to emphasize yield and gross margin was taking place on both process fronts.

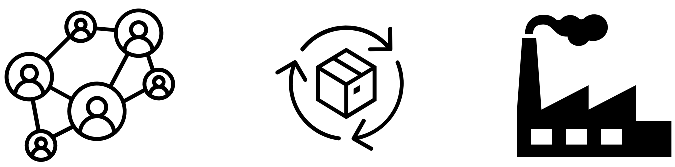


Figure 46 - Area Inclusion

4.1.2. Mold recovery

An action plan for the recovery and reconstruction of the agglomeration line molds was the next improvement action to be addressed, and it had a significant influence on block yield.

Below, in Figures 47, 48 and 49, we can see from the supplied photos some samples of what these might bring troublesome in order to better understand the influence that these can have on the design and performance of the blocks.

Figure 47 - Condition of the blocks using damaged molds 1.

Figure 48 - Condition of the blocks using damaged molds 2.

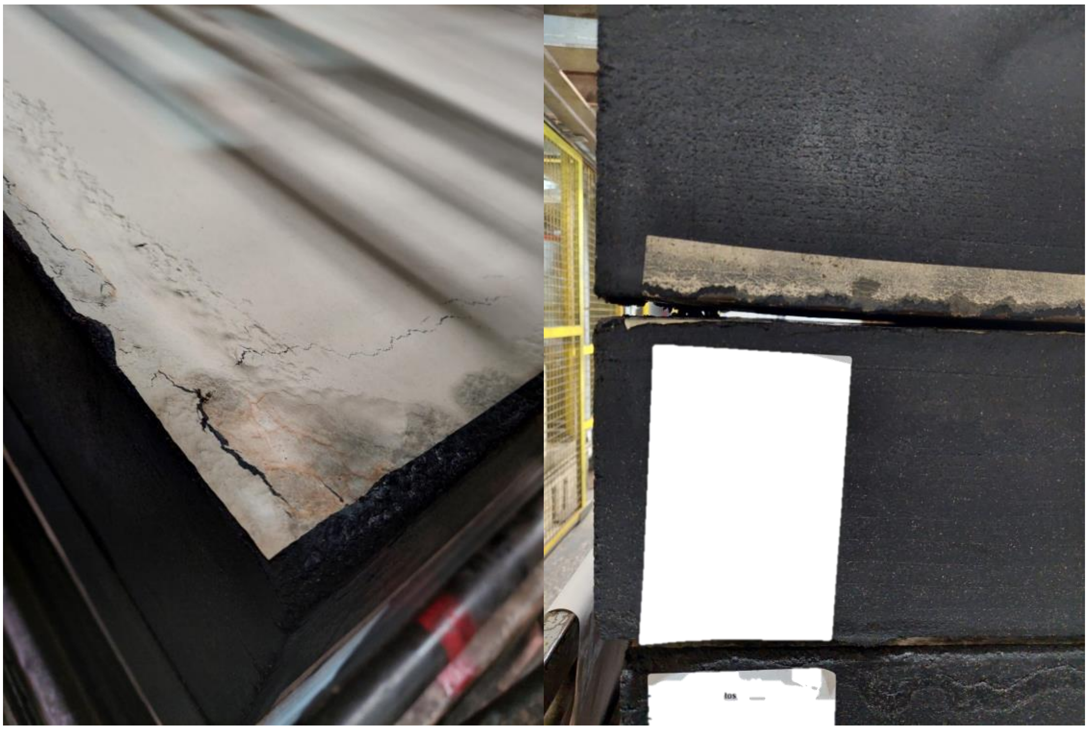


Figure 49 - Condition of the blocks using damaged molds 3.

As can be seen, the blocks can be significantly impacted by the molds used in their design, leading to abnormalities in the block bases, inadequate block height, oval blocks with non-perpendicular neighboring edges, and overall varying dimensions in different parts of the block. With the emergence of these traits, the cleaning procedure undertaken prior to the extraction of slabs will need to be more extensive and time-consuming, necessitating further cleaning passes to make the block consistent. As a result, the block will unavoidably be shorter than blocks without these issues. The block where the block was built has a direct bearing on how well it performs.

The molds have these issues because they have been in use for many generations, are polluted, have warped and fractured sides, and have issues fitting dowels since they have been used frequently and never been fixed. In the examples provided below, through Figures 50 and 51 we can see some of these.

Figure 50 - Condition of molds 1.

Figure 51 - Condition of molds 2.

According to the information provided, a strategy was developed with the intention of making 379 interventions in these molds in order to raise the caliber of the blocks at the agglomeration's departure. The number of molds for each dimension and feature is shown in the Figure 52 below.

Mold	Nº
CAE Aut (915x915)	60
CAE 5 Cav (915x915)	30
CAE 4 cav (915x915)	30
CAD (1270x760)	82
CAF (1000x1000)	77
CAH (1270x1040)	40
CAB (1270x660)	50
Rodas	10
TOTAL	379

Figure 52 - Nº of molds per type of molds

It was then planned the intervention in all the molds, with an estimated investment of 18 900.00€, 50€/mold, with an external company, in a workshop inside the company. The action plan was for 9 months and counted on a repair cadence of 10 molds per week, alignment made between the production team and the external storage team.

In order to better manage the intervention priorities in the first stage of this mold restoration project, an analysis was carried out to determine which blocks (size) had been most requested in the year 2022, Figure 53. This was done prior to the intervention phase, in a needs study phase, and with the aim of improving decision making supported by data.

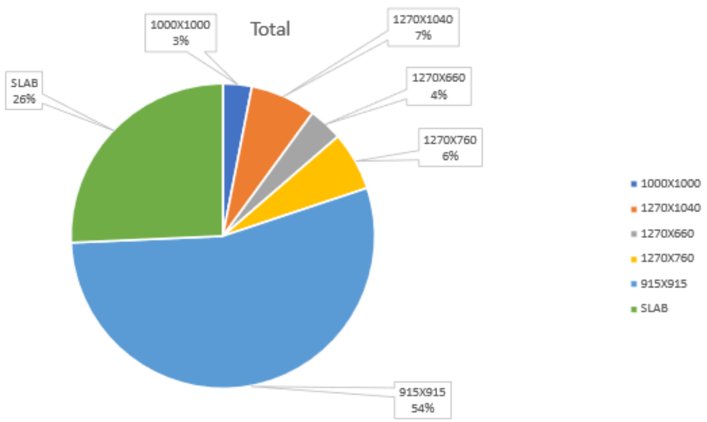


Figure 53 - Request mold dimensions study

Currently, the status of this mold repair and reconstruction action is 32% complete, around 120 molds have been completely repaired and €6,000.00 has been invested.

Below we see the current status per dimension in Figure 54.

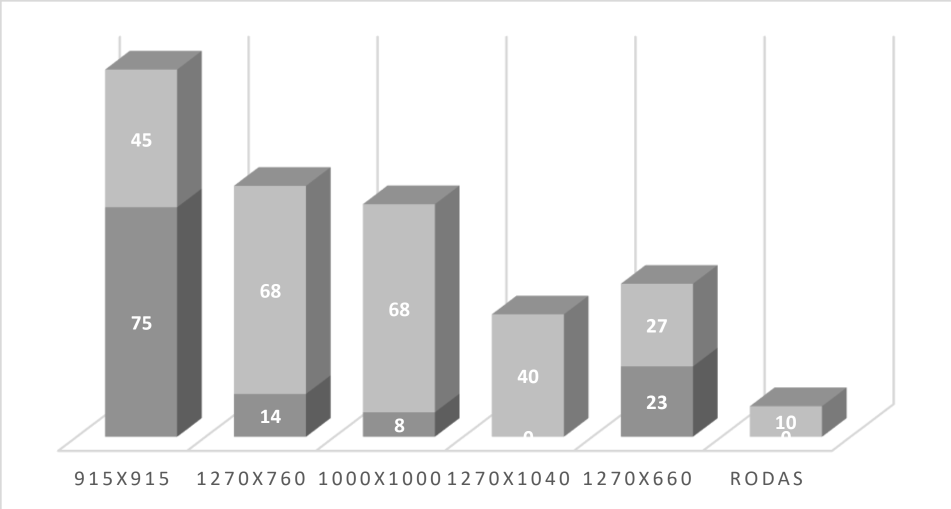


Figure 54 - Number of blocks intervened and still to be intervened (per dimension)

Multiple aspects that were not taken into consideration at an early design stage are the cause of this departure from expectations. First and foremost, the weather conditions were a deciding issue since the external firm couldn't work on the molds in bad weather because the workshop is outdoors, has limited space, and stores the molds outside. In this fashion, there were weeks when the plan's fulfillment was completely put at risk, causing a significant delay. The lack of coordination between the two teams, manufacturing and maintenance, was another factor that affected the action deadline. With the variability of production and repair capacity, and in order not to interfere with the lead time, we had weeks in which the expected molds could not be transported to the repair area and, conversely, in many weeks the maintenance team did not have availability to receive the stipulated because they had other tasks pending in the factory.

though it wasn't a planned action in this project, the purchase of new molds was influenced in its genesis thanks to this action plan in improving the performance of the blocks and repairing/rebuilding molds. With the weekly meetings that were created with the project, the validation of the designs and inputs for the purchase of new molds were something that emerged after these meetings, leading to more efficient molds and with lower failure potentials than the degraded molds. Thus, it is expected that these will have a decisive impact on the blocks and their performance.

The purchase of these molds, Figure 55, which in total are 35, began on April 9 and counted on the arrival of 4 molds per week during 2 months. The purchase focused on the 915X915 mm, since, as previously discussed, they are the ones that have more output for the production and customer.

Figure 55 - New purchased molds

We measured the blocks in three different locations—at the front of the mold, in the middle, and in the rear of the mold—in order to better understand the effects of this mold recovery approach and the acquisition of new molds on the blocks' final performance. This investigation was conducted at the beginning of the transformation, with the block unaltered after it was removed from the mold, of the blocks after the first cleaning phase, with the uniformization of one of the block's bases, and after the second cleaning phase, with the block operational and the final yield. Examples of these measurements, which were made over the course of a month with 200 samples overall, are shown in Figure 56 below.

Ref.	Size	Nº Mold	Measurement Before Rolling			σ	Measurement after the first pass			Measurement after the second pass		
			Front	Middle	Rear		Front	Middle	Rear	Front	Middle	Rear
2549	915x915	82	157	159	158	1	154	154	155	150	150	150
2549	915x915	120	158	160	160	1,15	155	156	154	150	150	150
1049	1000x1000	35	165	160	160	2,88	160	159	160	154	154	154
1521	1270X1040	25	155	157	156	1	151	152	153	146	146	146
1521	1270X1040	52	160	161	160	0,57	152	151	153	146	146	146

Figure 56 - Blocks dimensions study

With these measurements, we plot the standard deviation of the heights of the 3 different positions in the mold, in order to verify the variability with which the heights present at the exit of the block from the agglomeration and correlate with the final yield, after the second cleaning pass, in order to verify the implications of the molds on the blocks.

In order to properly visualize the findings, we came to the following conclusions using Power BI, presented in Figure 57.

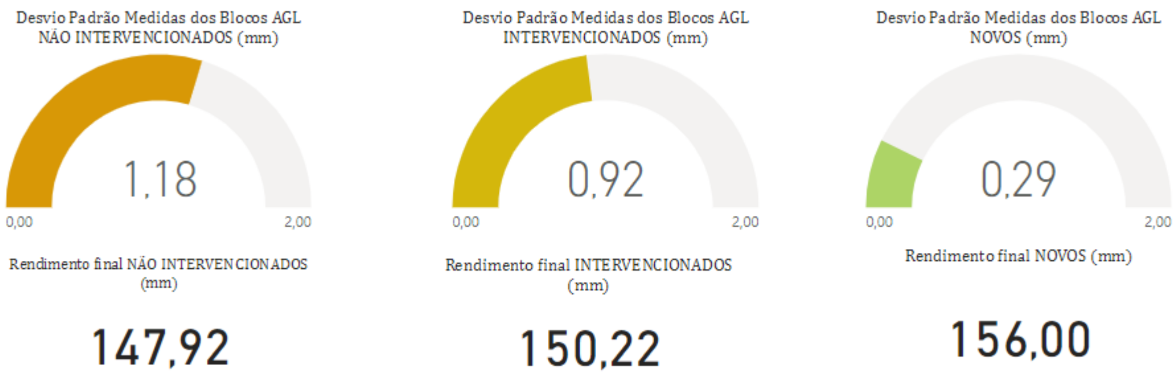


Figure 57 - Study's results

As we can see, the standard deviation in the measurements of the 3 block zones, represented at the top, is very high in the non-intervention molds (left), with a standard deviation greater than 1mm. Following the project, the ones with intervention (center) already have a more conforming standard deviation of less than 1mm. In turn, in the new molds, the variability is minimal, with 0.29 mm of standard deviation, which in theory will lead to a lower cleaning action, since the blocks are already more uniform in their essence.

Consequently, at the bottom, we can obtain the average yield of the measurements for each type of mold in which the blocks were produced. Analyzing the data, it is possible to affirm a dependency between the standard deviation data of blocks at the exit of the agglomeration and their final yield. With the intervention of old molds, the performance stipulated by the engineering team of 150mm was achieved, compared to the insufficient 147.92 mm of average presented by the non-intervened molds, justifying the bet on the recovery and intervention of molds in the IU 3 agglomeration line. Consequently, the improvement in performance becomes even more pronounced when it comes to the blocks manufactured using newly designed molds, surpassing the anticipated outcomes within the field with an average height of 156mm.

As a result, this improvement initiative emerged as the primary factor that directly influenced the production efficiency of achieving greater uniformity in blocks, thereby leading to increased yield.

4.1.3. Information flow improvements

Improving the information flow within an organization is a critical endeavor that can have far-reaching positive effects. By streamlining and enhancing the flow of information, organizations can promote better collaboration, decision-making, and overall efficiency.

Given the poor use of data that had never been analyzed, studied, or used as the motto for some kind of intervention or informative character, the area felt the need to improve communication and consultation in order to involve the area as a whole, leading to a greater focus on objectives. This was done in conjunction with the income project that was carried out. Theoretically, this focus will result in better opportunities and advancements.

In this regard, a number of initiatives were created to enhance the poor information flow, which frequently occurred between teams, departments, and senior management. These efforts employed Power BI, a program for data presentation, as their primary tool since it is popular in corporate settings and helps with data analysis and comprehension.

As was already mentioned, OPLs (One Point Lessons) were developed for the work centers on specific activities and procedures like block cleaning rules, how to correctly perform reversals, and how to tune the rolling mills in order to increase the standardization of specific processes in the slab rolling area. Internal communication was also thought to be necessary in order to engage the operators in the topic of intervention in block yield and gross margin. Consequently, some of these that were discussed are shown below in Figure 58, 59 and 60.

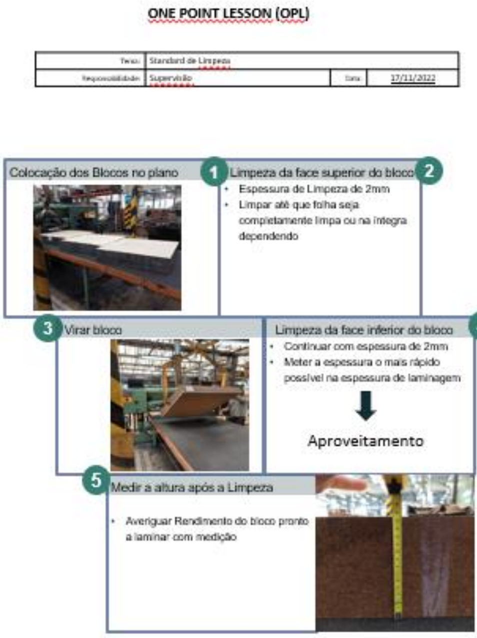


Figure 58 - OPL 1

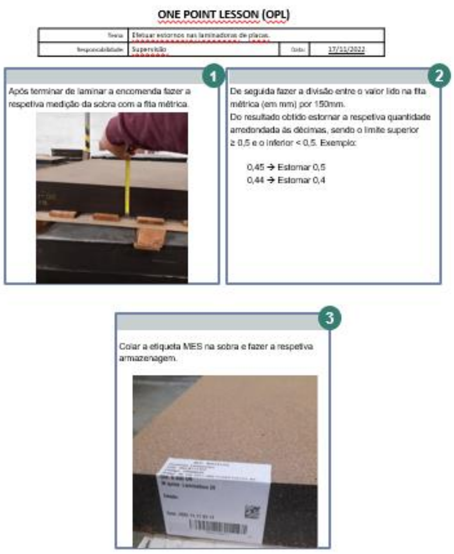


Figure 59 - OPL 2

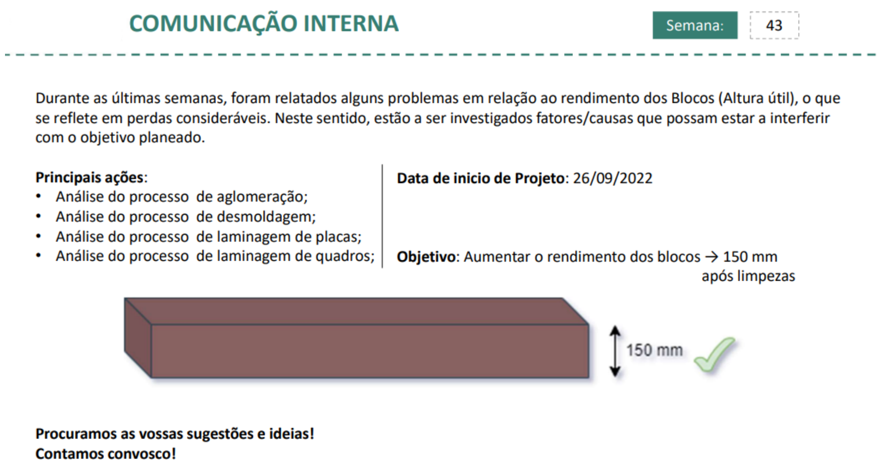


Figure 60 - Internal Communication

The creation of a Power BI dashboard that gave team members more control over it was another move done to build and promote collaboration on information, the scheduling of tasks, and the overall status of the block yield project. The following Figure 61 shows the interface. Together with Microsoft Planner, this was another support tool for the project.

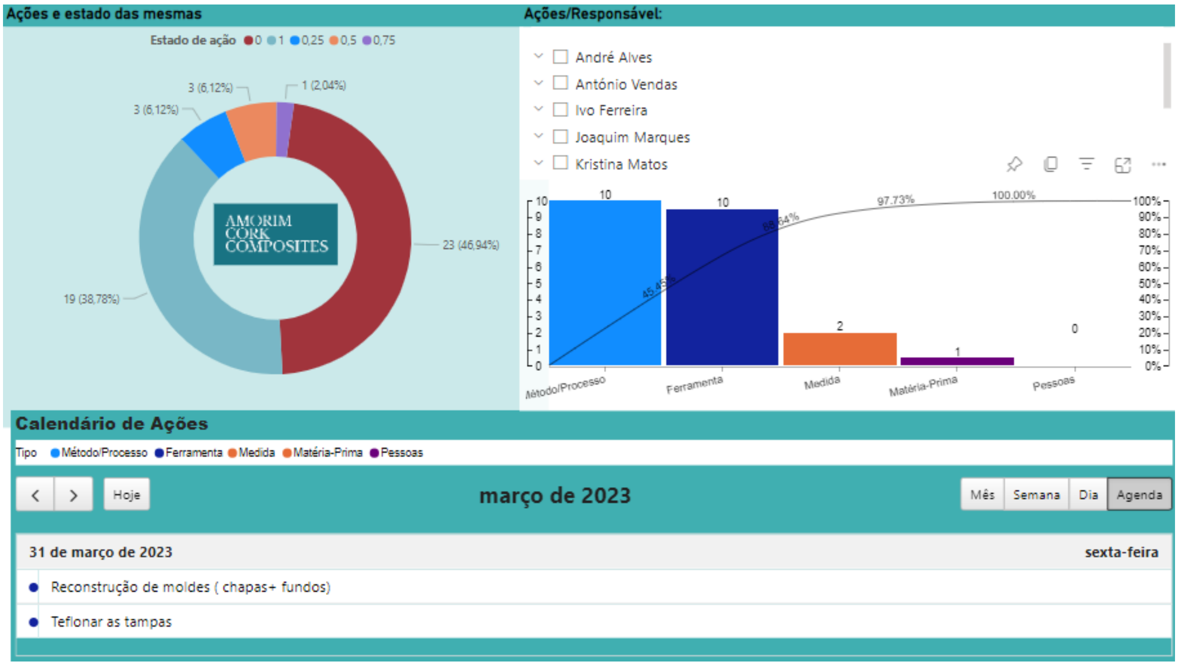


Figure 61 – Project’s BI dashboard

It was essential to develop a consultation dashboard in relation to the mold recovery and reconstruction project so that the project's participants could determine if a block was made using a mold that had been reworked, not reworked, or new by calling the number listed on the label of the block. With this, individuals in charge may immediately determine if the molds that led to the manufacture of the block through the inputs supplied concerning difficulties linked to rejection, yield, or poor production. This survey was conducted manually in the past because all of the inputs were on paper sheets. In addition, the dashboard made it easy to track the project's progress as well as the amount previously invested, the percentage of intervention by mold size, and the overall % of intervention. Therefore, its interface is below in Figure 62.

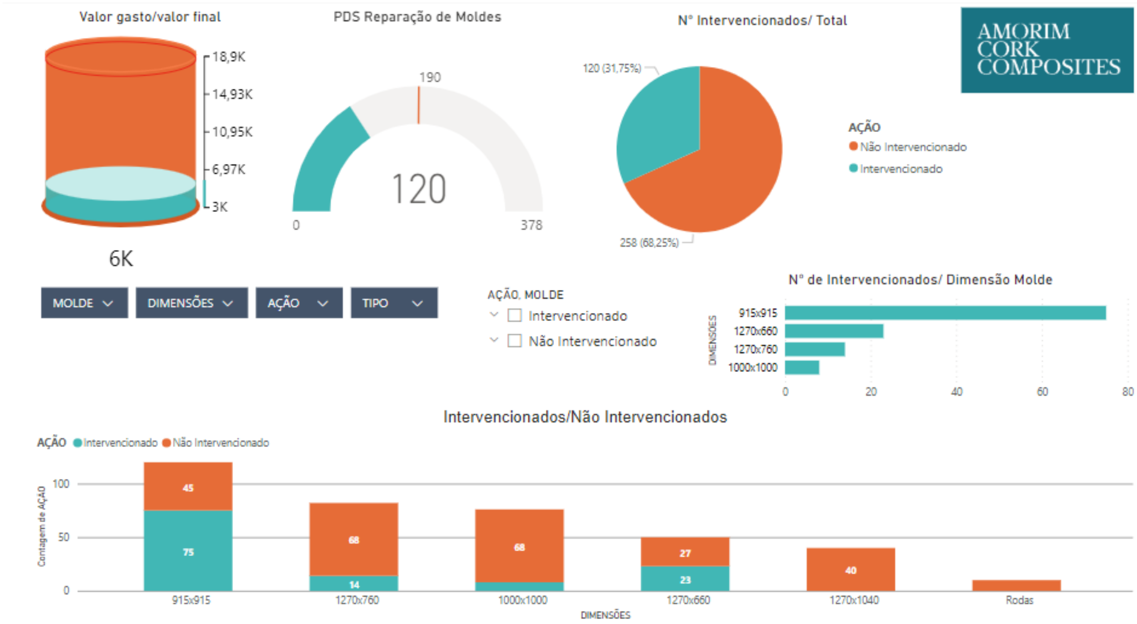


Figure 62 - Mold recovery BI dashboard

As previously stated, for the measurements in relation to block yield, an excel file was created in order to guarantee block measurements in the rolling mill according to block size and mold number information. This database was linked to a file in Power BI in order to provide the results of these measurements in permanent update. With this, the following dashboard was created as we can see in Figure 63.

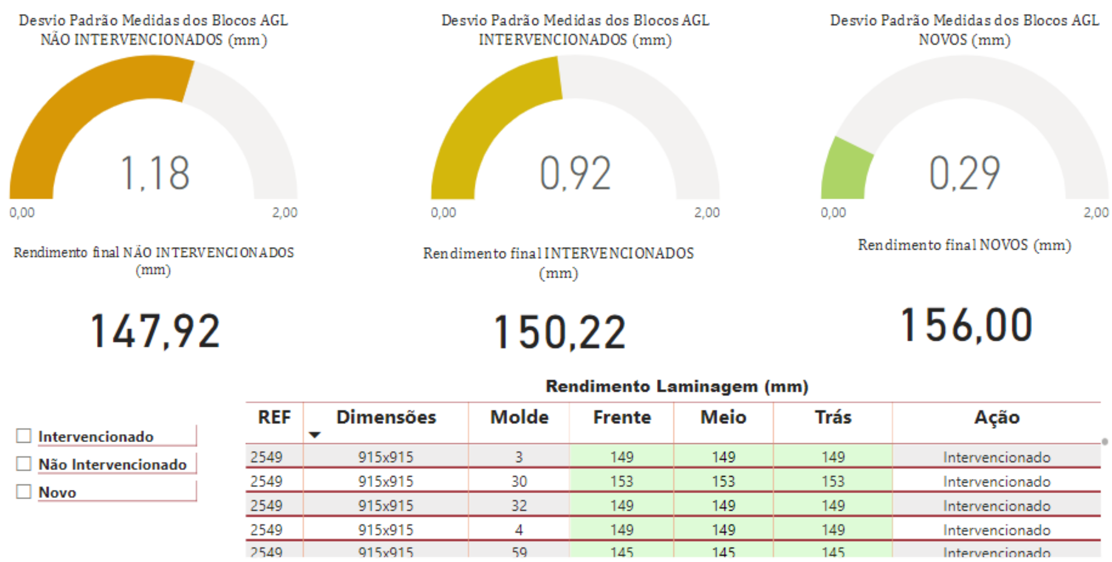


Figure 63 - Blocks yield study BI dashboard

All these efforts have culminated in a significant improvement in the existing flow of information in IU 3, with greater proactivity, control capacity and intervention.

4.1.4. Development of a deviation control tool

One of the most important factors in maximizing resource use and supporting sustainable practices is controlling consumption during manufacturing. Organizations may decrease waste, save expenses, and improve overall operational efficiency by carefully monitoring and regulating usage. Through data collection and analysis, organizations can identify areas of excessive consumption or inefficiency.

It became necessary in this situation to monitor and notify any variations in the production orders in the plate rolling area due to the yield, rejection, and data insertion issues that were affecting IU 3's processing area, utilizing data with MES (Manufacturing Execution System) assistance. By doing this, it is possible to have a better capacity to see mistakes, a daily control of production variances, and subsequently a better ability to respond to any quality and data insertion issues. To achieve this, the improvement action's concept was to develop an Excel tool that could show summaries of production at the involved work center and, in accordance with consumption and anticipated output, look into discrepancies in the number of blocks consumed and their financial impact. In order to ensure that this data is a regular part of the UI's daily routine, as soon as this excel tool is complete, a Power BI dashboard would be established for automated updating and emailing to upper management. As it is creative inside the organization and has the potential to be expanded to other regions and work centers, this improvement activity will have the most influence on the project's subject.

MES (Manufacturing Execution System) is a comprehensive software solution designed to optimize and manage manufacturing operations on the shop floor. It serves as a bridge between the enterprise resource planning (ERP) system and the plant floor, providing real-time visibility, control, and coordination of various production activities. MES, Figure 64, enables organizations to streamline their manufacturing processes, improve efficiency, and make data-driven decisions. With real-time importing of information about production in the factory, done by the operators through the MES, these are collected and used for shop floor analysis. Consequently, in excel they were worked in order to generate the desired tool.

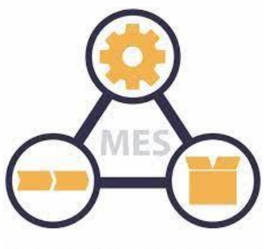


Figure 64 - MES

With real-time importing of information about production in the factory, done by the operators through the MES, these are collected and used for shop floor analysis. Consequently, in excel they were worked in order to generate the desired tool.

Next we can see an example of a daily report (05/16/2023) of summary of consumptions and productions, the tool developed, in the Rolling Blocks area of the UI 3 in Figure 65.

Total de Desvio		
	1º turno	113,15 €
	2º turno	547,30 €
	3º turno	835,16 €

ShiftName	OrderSap	SystemAltName	MaterialKey	MaterialName	Produções	Consumo Real	Consumo Planeado	Produção Planeada	Consumo teórico para a produção realizada	Desvio (bl)	Desvio
ACC_Geral3T_Turno1	1600171098	Laminadora 20	70009605	PL CR GT56 000 1270X760X2,1 NE	1 453,00	21,00	21,60	1456,00	21,56	-0,56	-222,95 €
ACC_Geral3T_Turno1	1600206994	Laminadora 21	70013755	PL CI 5025 000 1040X1040X1,9 NE	1 337,00	22,30	36,09	2433,00	19,83	2,47	338,32 €
ACC_Geral3T_Turno1	1600208742	Laminadora 20	70013740	PL CR 1521 000 1270X660X2,4 NE	60,00	1,00	1,01	60,00	1,01	-0,01	-2,22 €
ACC_Geral3T_Turno2	1600212215	Laminadora 21	70006248	PL CR 1047 000 1000X1000X10,0 NE	146,00	10,00	42,40	600,00	10,32	-0,32	-131,99 €
ACC_Geral3T_Turno2	1600212247	Laminadora 21	70006454	PL CR N650 000 1270X1040X8,0 NE	2,00	0,20	1,02	18,00	0,11	0,09	64,76 €
ACC_Geral3T_Turno2	1600212250	Laminadora 21	70009564	PL CR N650 000 1270X1040X9,0 NE	16,00	1,56	1,02	16,00	1,02	0,54	404,49 €
ACC_Geral3T_Turno2	1600213217	Laminadora 21	70028694	PL CR 4006 T01 915X915X1,0 NE	107,00	1,00	1,98	291,00	0,73	0,27	130,98 €
ACC_Geral3T_Turno2	1600213412	Laminadora 20	70010147	PL CI 5025 000 1040X1040X0,8 NE	392,00	3,00	52,78	8537,00	2,42	0,58	79,06 €
ACC_Geral3T_Turno3	1600207026	Laminadora 20	70006076	PL CR 1523 000 1000X1000X3,9 NE	379,00	12,00	79,99	2925,00	10,36	1,64	561,47 €
ACC_Geral3T_Turno3	1600207026	Laminadora 28	70006076	PL CR 1523 000 1000X1000X3,9 NE	108,00	3,00	79,99	2925,00	2,95	0,05	15,98 €
ACC_Geral3T_Turno3	1600212215	Laminadora 28	70006248	PL CR 1047 000 1000X1000X10,0 NE	118,00	9,00	42,40	600,00	8,34	0,66	274,20 €
ACC_Geral3T_Turno3	1600213217	Laminadora 28	70028694	PL CR 4006 T01 915X915X1,0 NE	148,00	1,00	1,98	291,00	1,01	-0,01	-3,38 €
ACC_Geral3T_Turno3	1600213412	Laminadora 20	70010147	PL CI 5025 000 1040X1040X0,8 NE	250,00	1,45	52,78	8537,00	1,55	-0,10	-13,12 €

Figure 65 - Created daily report

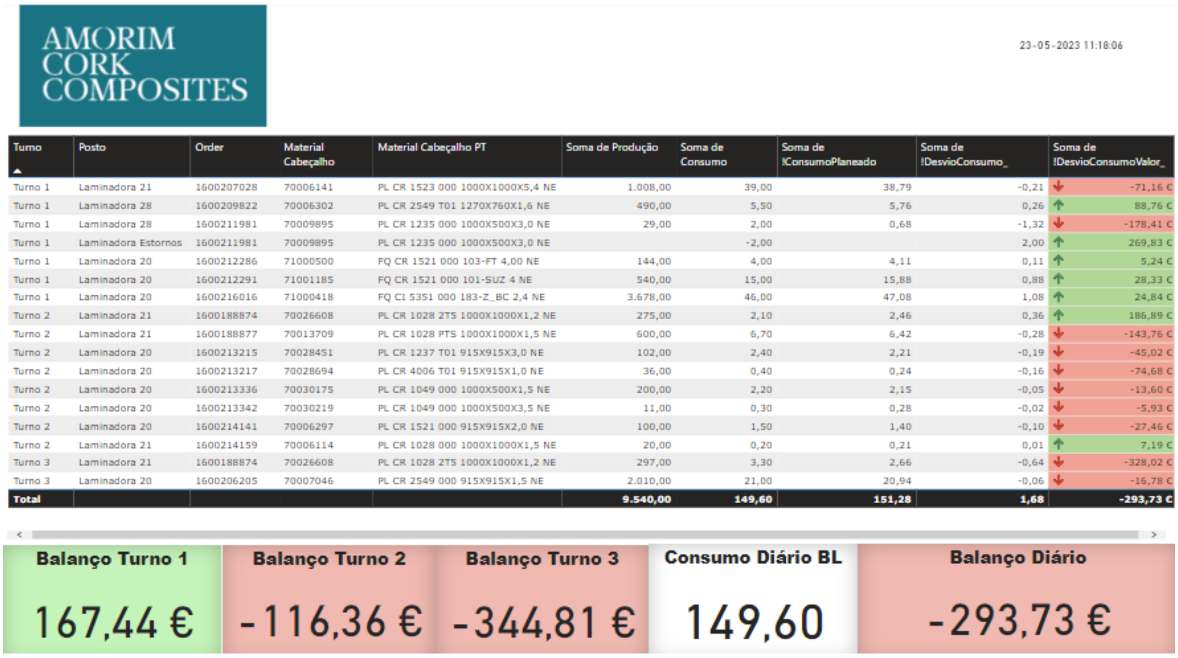
Analyzing the report, we can see the following information:

- Manufacturing order number.
- Reference and material number.
- Production shift.
- Plates produced.
- Consumption and planned production.
- Real consumption and theoretical consumption.
- Block variance and financial impact.

With this, we can summarize the amount of money that each shift's area made or lost in comparison to what it should have made if consumption followed the system's predictions. If so, there would be no variance, and each manufacturing order's value would be zero.

This tool became very important in the fight against these reported deviations, allowing us to act and understand the causes that led to it, even for potential defects in the insertion of data by operators that sometimes led to a deviation not congruent with reality. However, this same tool brought to light a flaw that had not yet been resolved, which prevents the region from ever being able to fulfill the consumption targets set out in the system. Since the maximum accuracy for the block consumption register is done in decimals, this problem is based on the decimals that differ between the system and the shop floor because for the majority of rolling mill production, the planned consumption for the manufacturing orders goes to hundredths and, this is something that the operators can't measure. For instance, the system projected that it would take 0.11 blocks to make 2 slabs for manufacturing order 1600212247. However, the operator will invariably enter that the consumption was 0.1 or 0.2, which will result in an incoherent divergence. The typical gross margin prediction for the region may be affected by the variations felt in the insertion, which would make it more challenging to achieve this objective. As a result, a study is being carried out within the organization to confirm and assess the effect of the issue, which was discovered using this reporting mechanism.

In the following stage of the project, we attempted to make this excel tool into something that could function and report without human input. This idea came about since it needed to be updated daily and reporting was carried out in a highly ineffective manner by sending print screens to each team member's email and the top management of the UI 3. Along with this, we also desired enhanced data display. Then, in order to meet these requirements, a dashboard was created using Power BI, a tool that is frequently used by the corporation and by companies in general. To do this, the DAX language was introduced with the assistance of knowledgeable individuals in order to aggregate and modify the data flowing from the MES. Below in Figure 66 is of how this activity turned out.



23-05-2023 11:18:06

Turno	Posto	Order	Material Cabeçalho	Material Cabeçalho PT	Soma de Produção	Soma de Consumo	Soma de !ConsumoPlaneado	Soma de !DesvioConsumo_	Soma de !DesvioConsumoValor_
Turno 1	Laminadora 21	1600207028	70006141	PL CR 1523 000 1000X1000X5,4 NE	1.008,00	39,00	38,79	-0,21	-71,16 €
Turno 1	Laminadora 28	1600209822	70006302	PL CR 2549 T01 1270X760X1,6 NE	490,00	5,50	5,76	0,26	88,76 €
Turno 1	Laminadora 28	1600211981	70009895	PL CR 1235 000 1000X500X3,0 NE	29,00	2,00	0,68	-1,32	-178,41 €
Turno 1	Laminadora Estornos	1600211981	70009895	PL CR 1235 000 1000X500X3,0 NE		-2,00		2,00	269,83 €
Turno 1	Laminadora 20	1600212286	71000500	FQ CR 1521 000 103-FT 4,00 NE	144,00	4,00	4,11	0,11	5,24 €
Turno 1	Laminadora 20	1600212291	71001185	FQ CR 1521 000 101-SUZ 4 NE	540,00	15,00	15,88	0,88	28,33 €
Turno 1	Laminadora 20	1600216016	71000418	FQ CI 5351 000 183-Z_BC 2,4 NE	3.678,00	46,00	47,08	1,08	24,84 €
Turno 2	Laminadora 21	1600188874	70026608	PL CR 1028 2TS 1000X1000X1,2 NE	275,00	2,10	2,46	0,36	186,89 €
Turno 2	Laminadora 21	1600188877	70013709	PL CR 1028 PTS 1000X1000X1,5 NE	600,00	6,70	6,42	-0,28	-143,76 €
Turno 2	Laminadora 20	1600213215	70028451	PL CR 1237 T01 915X915X3,0 NE	102,00	2,40	2,21	-0,19	-45,02 €
Turno 2	Laminadora 20	1600213217	70028694	PL CR 4006 T01 915X915X1,0 NE	36,00	0,40	0,24	-0,16	-74,68 €
Turno 2	Laminadora 20	1600213336	70030175	PL CR 1049 000 1000X500X1,5 NE	200,00	2,20	2,15	-0,05	-13,60 €
Turno 2	Laminadora 20	1600213342	70030219	PL CR 1049 000 1000X500X3,5 NE	11,00	0,30	0,28	-0,02	-5,93 €
Turno 2	Laminadora 20	1600214141	70006297	PL CR 1521 000 915X915X2,0 NE	100,00	1,50	1,40	-0,10	-27,46 €
Turno 2	Laminadora 21	1600214159	70006114	PL CR 1028 000 1000X1000X1,5 NE	20,00	0,20	0,21	0,01	7,19 €
Turno 3	Laminadora 21	1600188874	70026608	PL CR 1028 2TS 1000X1000X1,2 NE	297,00	3,30	2,66	-0,64	-328,02 €
Turno 3	Laminadora 20	1600206205	70007046	PL CR 2549 000 915X915X1,5 NE	2.010,00	21,00	20,94	-0,06	-16,78 €
Total					9.540,00	149,60	151,28	1,68	-293,73 €

Figure 66 - Daily control deviation production tool BI dashboard

Currently, this dashboard is operational and flawless, requiring no human intervention to refresh the data and deliver it to the team members.

It was necessary to provide the same daily reporting tool to the work center in order to involve the operators in this management of consumption discrepancies in the processing area. This was crucial so that the entire area could be involved, and the operators could comprehend the effects that these deviations had on the area and how even a relatively minor deviation might have a big impact. Posting the relevant information on the Slab Rolling area's Kaizen Board every day was necessary for this. As a result of this move, the production area's routines and attitudes changed, and the operators were forced to notify the supervisors of any deviations because of the potential effects they might have on the area and their shift.

Thus, in Figure 67 and 68 we can see the report presented in the *gemba*.

Turno 1	291,45 €
Turno 2	475,67 €
Turno 3	112,83 €

Responsável Atualização: Supervisão

Periodicidade de Atualização: Diária

Semana	
21	23/05/2023
	879,95 €

AMORIM CORK COMPOSITES

Turno	OF	CT	MATERIAL	MATERIAL NAME	PRODUÇÃO PL	CONSUMO BL	CONSUMO TEÓRICO BL	DESVIO BL	DESVIO €
1	1600188874	Laminadora 21	70026608	PL CR 1028 2T5 1000X1000X1,2 NE	70	0,6	0,63	-0,03	-13,97 €
1	1600200164	Laminadora 21	70006111	PL CR 1028 2T5 1000X1000X1,05 NE	312	2,4	2,33	0,07	35,45 €
1	1600206205	Laminadora 20	70007046	PL CR 2549 000 915X915X1,5 NE	669	7	6,97	0,03	8,73 €
1	1600207028	Laminadora 20	70006141	PL CR 1523 000 1000X1000X5,4 NE	112	4,6	4,31	0,29	99,45 €
1	1600207030	Laminadora 20	70006142	PL CR 1523 000 1000X1000X6,0 NE	36	1,4	1,50	-0,10	-33,01 €
1	1600209822	Laminadora 28	70006302	PL CR 2549 T01 1270X760X1,6 NE	90	1	1,06	-0,06	-19,82 €
1	1600212383	Laminadora 28	70009480	PL CR S112 PT1 1000X1000X10,0 NE	15	1	1,02	-0,02	-12,26 €
1	1600212708	Laminadora 28	70006174	PL CR 1237 000 1000X1000X4,8 NE	100	3,5	3,33	0,17	45,69 €
1	1600212745	Laminadora 28	70007013	PL CR 1237 000 1000X1000X2,5 NE	100	1,7	1,72	-0,02	-5,64 €
1	1600213351	Laminadora 28	70007106	PL CR 2549 000 1000X1000X2,0 NE	300	4,7	4,17	0,53	186,83 €
2	1600188873	Laminadora 21	70010003	PL CR 1028 PTS 1000X1000X1,0 NE	450	3,48	3,21	0,27	137,60 €
2	1600202891	Laminadora 20	70006576	PL CR N650 PTH 1270X1040X3,0 NE	25	0,5	0,51	-0,01	-6,72 €
2	1600206883	Laminadora 20	70007583	PL CR RU04 000 1270X1040X1,0 NE	128	1,4	0,99	0,41	344,78 €
3	1600188874	Laminadora 21	70026608	PL CR 1028 2T5 1000X1000X1,2 NE	301	3	2,70	0,30	155,59 €
3	1600206205	Laminadora 20	70007046	PL CR 2549 000 915X915X1,5 NE	2029	21	21,14	-0,14	-42,76 €

Figure 67 - Deviation Control used in the daily Kaizen area

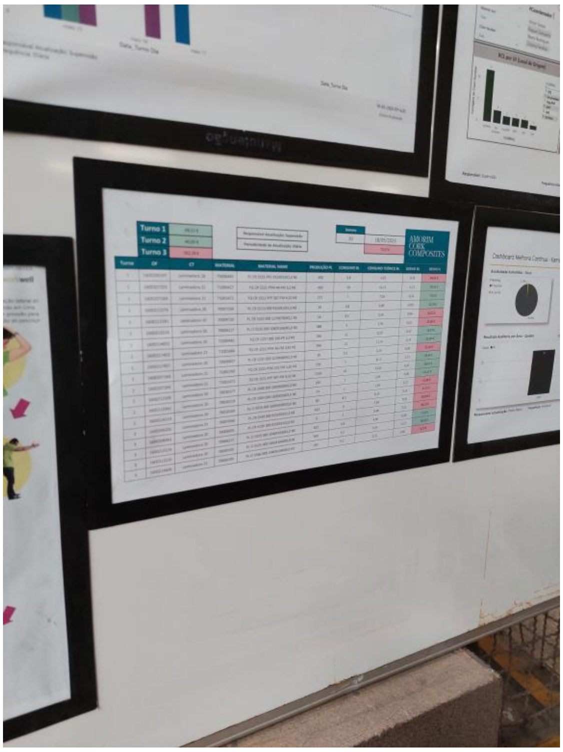


Figure 68 - Deviation Control used in the daily Kaizen area 2

4.2. Analysis of Results

The outcomes of this project resonate with significant impact, highlighting several notable achievements. These achievements extend beyond mere operational enhancements, firmly aligning with the core principles derived from our extensive literature review on Industry 4.0 and Lean methodologies. In essence, this research has manifested as a dynamic catalyst for progress, illustrating how it amplifies the value proposition.

Primarily, the project's thrust toward improved information flow and heightened stakeholder engagement materialized through the development of dashboards, streamlined communication, and the standardization of critical processes within the agglomeration and transformation realm. This trajectory, marked by substantial achievements, notably bolstered block yields, consequently enhancing gross margins. By maximizing the utilization and extraction of finished products, particularly in the transformation of blocks into slabs, we found ourselves achieving higher production capacities, effectively bridging the gap between industry 4.0 and Lean principles.

Furthermore, our study spurred the introduction of novel monitoring and analysis technologies within the plant. This innovation, serving as a testament to the project's transformative value, empowers real-time tracking of production and resource consumption within specific areas. Such advancements indirectly contribute to heightened intervention capabilities and more precise issue detection. These technological leaps underscore the nexus between Industry 4.0 advancements and the inherent benefits of Lean principles, translating into enhanced operational efficiency.

In a broader context, this project emerges as a vital contributor to the improvement of IU 3 within the 6 M's of Ishikawa. While tangibility in financial terms may prove elusive due to various intertwined factors, such as ongoing mold issues, escalating quality deviations, and inflation-induced cost increments, the value brought to the scientific community and the industry at large remains undeniable. By seamlessly integrating Industry 4.0 and Lean principles into an industrial context, this research advances our understanding of the practical implementation of these concepts. Its significance reverberates not only as a testament to the potential synergies between these two pillars but also as an invaluable resource for the scientific community, forging new pathways toward operational excellence and innovation within the field.

Figure 69 - Analysis of Results

4.3. Discussion

The significance of this research goes far beyond its immediate effects on the cork block production business, as it serves as an example of the revolutionary potential of integrating business 4.0 with Lean Management, which can produce wide-ranging benefits with ramifications for numerous industries.

The impressive increase in cork block yield attained through the extensive "Yield Project" carried out in the Industrial Unit is the most notable of the value enhancements. These outcomes not only meet predetermined expectations, but they also closely follow the prescriptions made in the literature review. By streamlining procedures, utilizing real-time data, and fostering a culture of continuous improvement, this study serves as a light of excellence that cuts across sector borders.

Furthermore, the standardized assets that this thesis introduces into numerous procedures via data enhancements highlight its contribution to the field of scientific investigation. The development of user-friendly dashboards, the improvement of data flow, and the application of the deviation control tool provide companies with vital models for quality control and data-driven decision-making. An indication of the disruptive potential of combining Lean and Industry 4.0 concepts in the digital era is the emphasis on cutting-edge technologies and real-time monitoring.

In conclusion, this study offers insights into the ground-breaking possibilities of integrating Industry 4.0 with Lean Management and serves as an inspirational resource for academics, industry professionals, and enterprises alike. Although its contributions serve as a testament to the industry 4.0 and Lean concepts' continued applicability in promoting innovation, sustainability, and excellence on a global scale, their worth goes beyond operational improvements. This integration has the power to transform and reinvent established sectors, ushering in a new era of productivity, adaptability, and competition that goes beyond the confines of the cork block manufacturing industry. This transformation is particularly important because it demonstrates how Lean 4.0 principles can be applied across a variety of industrial disciplines, highlighting their potential to spark good change in the larger economic environment. However, it is important to recognize that additional study and adaptation may be necessary to fully harness these principles' transformative power in a variety of contexts, a route that presents great chances for future discovery and growth.

5. CONCLUSION

This chapter is aimed to give a general overview of the project, as well as the added value it generated for the participants and the company, and to make any final observations. It will also go through any potential follow-up work I think is important for this project.

5.1. Final conclusions

In conclusion, this thesis marks a critical turning point for the cork block sector because to the outstanding outcomes attained in a number of crucial areas. It was feasible to increase the production of cork blocks through a collaborative improvement effort, resulting in real advantages for the business. This accomplishment was greatly helped by the remodeling and rebuilding of the molds, which made the process more effective and reliable. Additionally, the company's improved information flow had a significant impact, enabling faster and more accurate access to and consultation of data. The adoption of a cutting-edge deviation control tool has increased process management efficiency by enabling the early detection of issues and the deployment of remedial actions. This project, developed in an industrial setting, has a special significance for me since it allowed me to directly use the academic knowledge I had acquired. My passion for the industrial engineering field and the significance of applied research were reinforced by the opportunity to work in collaboration with experienced professionals and testify firsthand to the positive results achieved.

5.2. Limitations and future work

Limitations and future work for the thesis include the following:

Full implementation of the mold recovery plan: The ongoing process of implementing the mold recovery plan has shown significant improvements in block yield, as demonstrated by the obtained results. However, further efforts are needed to ensure the complete implementation of the plan, which would lead to impactful improvements in yield for all molds in the agglomeration line.

Application of the deviation control tool to other work centers: The successful implementation of the deviation control tool in the current context opens up opportunities for its application in other work centers within the factory, such as the roll lamination area and other relevant industrial areas. Extending the use of the tool to these areas could lead to additional improvements and efficiency gains.

Periodic yield control audits: Implementing periodic audits specifically focused on yield control would provide a systematic approach for verification and early detection of any potential issues or deviations. Regular audits would contribute to a more efficient and timely response to any deviations from the desired yield levels, ensuring continuous improvement and process optimization.

Development of a mold maintenance plan: Considering the direct impact of molds on block yield, the creation of a comprehensive mold maintenance plan is crucial. This plan would aim to prevent the degradation and deterioration of molds, ensuring their optimal condition and performance. By implementing a proactive maintenance strategy, the negative effects on block yield caused by mold degradation can be mitigated, further enhancing overall production efficiency.

Addressing these limitations and pursuing the suggested future work will contribute to the ongoing improvement efforts and yield optimization in the production of cork blocks. These actions will enable the achievement of even better results and pave the way for continuous enhancements in the manufacturing process within the cork factory.

REFERENCES

[1] M. P. Groover, “Fundamentals of modern manufacturing : materials, processes, and systems,” p. 1012, 2010, Accessed: Sep. 10, 2023. [Online]. Available: https://books.google.com/books/about/Fundamentals_of_Modern_Manufacturing.html?hl=pt-PT&id=QU-Qvud3OvoC

[2] P. Sousa, A. Tereso, A. Alves, and L. Gomes, “Implementation of project management and lean production practices in a SME Portuguese innovation company,” *Procedia Comput Sci*, vol. 138, pp. 867–874, Jan. 2018, doi: 10.1016/J.PROCS.2018.10.113.

[3] “Presença Mundial - Corticeira Amorim - Corticeira Amorim, Líder Mundial Setor Cortiça.” Accessed: Jan. 07, 2023. [Online]. Available: https://www.amorim.com/pt/corticeira-amorim/presenca-mundial/?f_loc=EUA

[4] M. Brydon-Miller, D. Greenwood, and P. Maguire, “Why Action Research?,” *Action Research*, vol. 1, no. 1. 2003. doi: 10.1177/14767503030011002.

[5] D. C. Collatto, A. Dresch, D. P. Lacerda, and I. G. Bentz, “Is Action Design Research Indeed Necessary? Analysis and Synergies Between Action Research and Design Science Research,” *Syst Pract Action Res*, vol. 31, no. 3, 2018, doi: 10.1007/s11213-017-9424-9.

[6] W. Carr, “Philosophy, methodology and action research,” *Journal of Philosophy of Education*, vol. 40, no. 4, pp. 421–435, Nov. 2006, doi: 10.1111/J.1467-9752.2006.00517.X.

[7] G. I. Susman and R. D. Evered, “An Assessment of the Scientific Merits of Action Research,” *Adm Sci Q*, vol. 23, no. 4, 1978, doi: 10.2307/2392581.

[8] G. Santos *et al.*, “New needed quality management skills for quality managers 4.0,” *Sustainability (Switzerland)*, vol. 13, no. 11, 2021, doi: 10.3390/su13116149.

[9] A. Rojko, “Industry 4.0 concept: Background and overview,” *International Journal of Interactive Mobile Technologies*, vol. 11, no. 5, 2017, doi: 10.3991/ijim.v11i5.7072.

[10] E. Hofmann and M. Rüsch, “Industry 4.0 and the current status as well as future prospects on logistics,” *Comput Ind*, vol. 89, 2017, doi: 10.1016/j.compind.2017.04.002.

[11] H. Kagermann, W.-D. Lukas, and W. Wahlster, “Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution,” *VDI Nachrichten*, no. 13, 2011.

[12] H. Kagermann, W. Wahlster, and J. Helbig, “Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0. Abschlussbericht des Arbeitskreises Industrie 4.0. Hg. v. Promotorengruppe Kommunikation der Forschungsunion Wirtschaft – Wissenschaft und acatech.,” *Deutsche Akademie der Technikwissenschaften (acatech)*, no. April, 2013.

[13] “TRAI pushes for IoT services, better connectivity in NTP recommendation | MediaNama.” Accessed: Sep. 12, 2023. [Online]. Available: https://www.medianama.com/2018/02/223-trai-pushes-for-iot-services-better-connectivity-in-ntp-recommendation/

[14] F. Yu and T. Schweisfurth, “Industry 4.0 technology implementation in SMEs – A survey in the Danish-German border region,” *International Journal of Innovation Studies*, vol. 4, no. 3, 2020, doi: 10.1016/j.ijis.2020.05.001.

[15] G. Erboz, “How To Define Industry 4.0: Main Pillars of Industry 4.0,” *Managerial trends in the development of enterprises in globalization era*, no. November 2017, 2017.

[16] B. Pinto, F. J. G. Silva, T. Costa, R. D. S. G. Campilho, and M. T. Pereira, “A Strategic Model to take the First Step Towards Industry 4.0 in SMEs,” *Procedia Manuf*, vol. 38, pp. 637–645, Jan. 2019, doi: 10.1016/J.PROMFG.2020.01.082.

[17] M. T. Pereira, A. Silva, L. P. Ferreira, J. C. Sá, and F. J. G. Silva, “A DMS to support industrial process decision-making: A contribution under Industry 4.0,” in *Procedia Manufacturing*, 2019. doi: 10.1016/j.promfg.2020.01.079.

[18] E. Oztemel and S. Gursev, “Literature review of Industry 4.0 and related technologies,” *Journal of Intelligent Manufacturing*, vol. 31, no. 1. 2020. doi: 10.1007/s10845-018-1433-8.

[19] L. Barreto, A. Amaral, and T. Pereira, "Industry 4.0 implications in logistics: an overview," *Procedia Manuf*, vol. 13, 2017, doi: 10.1016/j.promfg.2017.09.045.

[20] Y. Cohen, M. Faccio, F. G. Galizia, C. Mora, and F. Pilati, "Assembly system configuration through Industry 4.0 principles: the expected change in the actual paradigms," 2017. doi: 10.1016/j.ifacol.2017.08.2550.

[21] D. Romero *et al.*, "Towards an operator 4.0 typology: A human-centric perspective on the fourth industrial revolution technologies," in *CIE 2016: 46th International Conferences on Computers and Industrial Engineering*, 2016.

[22] S. Vaidya, P. Ambad, and S. Bhosle, "Industry 4.0 - A Glimpse," in *Procedia Manufacturing*, 2018. doi: 10.1016/j.promfg.2018.02.034.

[23] Y. Wang, H. S. Ma, J. H. Yang, and K. S. Wang, "Industry 4.0: a way from mass customization to mass personalization production," *Adv Manuf*, vol. 5, no. 4, pp. 311–320, Dec. 2017, doi: 10.1007/S40436-017-0204-7/FIGURES/5.

[24] D. Ibarra, J. Ganzarain, and J. I. Igartua, "Business model innovation through Industry 4.0: A review," in *Procedia Manufacturing*, 2018. doi: 10.1016/j.promfg.2018.03.002.

[25] M. Hermann, T. Pentek, and B. Otto, "Design Principles for Industrie 4.0 Scenarios: A Literature Review," *Technische Universitat Dortmund*, vol. 1, no. 1, 2015.

[26] H. Meissner, R. Ilsen, and J. C. Aurich, "Analysis of Control Architectures in the Context of Industry 4.0," *Procedia CIRP*, vol. 62, pp. 165–169, Jan. 2017, doi: 10.1016/J.PROCIR.2016.06.113.

[27] M. Moghaddam, M. N. Cadavid, C. R. Kenley, and A. V. Deshmukh, "Reference architectures for smart manufacturing: A critical review," *J Manuf Syst*, vol. 49, pp. 215–225, Oct. 2018, doi: 10.1016/J.JMSY.2018.10.006.

[28] P. Gupta, "Modularity enablers: a tool for Industry 4.0," *Life Cycle Reliability and Safety Engineering*, vol. 8, no. 2, 2019, doi: 10.1007/s41872-018-0067-3.

[29] C. Bai, P. Dallasega, G. Orzes, and J. Sarkis, "Industry 4.0 technologies assessment: A sustainability perspective," *Int J Prod Econ*, vol. 229, p. 107776, Nov. 2020, doi: 10.1016/J.IJPE.2020.107776.

[30] M. A. K. Bahrin, M. F. Othman, N. H. N. Azli, and M. F. Talib, "Industry 4.0: A review on industrial automation and robotic," *Jurnal Teknologi*, vol. 78, no. 6–13. 2016. doi: 10.11113/jt.v78.9285.

[31] "Industry 4.0: Key concepts and digital technologies (source: Image... | Download Scientific Diagram." Accessed: Dec. 29, 2022. [Online]. Available: https://www.researchgate.net/figure/Industry-40-Key-concepts-and-digital-technologies-source-Image-created-by-author-C_fig1_349974274

[32] G. Erboz, "How to define industry 4.0: main pillars of industry 4.0," in *Managerial trends in the development of enterprises in globalization era*, 2017.

[33] L. Da Xu, E. L. Xu, and L. Li, "Industry 4.0: state of the art and future trends," *https://doi.org/10.1080/00207543.2018.1444806*, vol. 56, no. 8, pp. 2941–2962, 2018, doi: 10.1080/00207543.2018.1444806.

[34] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *Computer Networks*, vol. 54, no. 15, 2010, doi: 10.1016/j.comnet.2010.05.010.

[35] "Internet of Things (IoT)." Accessed: Dec. 30, 2022. [Online]. Available: https://www.linkedin.com/pulse/internet-things-iot-mohammad-alyasfo

[36] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys and Tutorials*, vol. 17, no. 4, 2015, doi: 10.1109/COMST.2015.2444095.

[37] W. Ji and L. Wang, "Big data analytics based fault prediction for shop floor scheduling," *J Manuf Syst*, vol. 43, 2017, doi: 10.1016/j.jmsy.2017.03.008.

[38] “The Origin of Big Data Analytics - Analytics Vidhya.” Accessed: Dec. 30, 2022. [Online]. Available: https://www.analyticsvidhya.com/blog/2022/09/the-origin-of-big-data-analytics/

[39] R. Y. Zhong, X. Xu, E. Klotz, and S. T. Newman, “Intelligent Manufacturing in the Context of Industry 4.0: A Review,” *Engineering*, vol. 3, no. 5, 2017, doi: 10.1016/J.ENG.2017.05.015.

[40] K. Candel Haug, T. Kretschmer, and T. Strobel, “Cloud adaptiveness within industry sectors - Measurement and observations,” *Telecomm Policy*, vol. 40, no. 4, 2016, doi: 10.1016/j.telpol.2015.08.003.

[41] “10 Types of Cloud Computing You Should Know About.” Accessed: Jan. 03, 2023. [Online]. Available: https://helpdeskgeek.com/reviews/10-types-of-cloud-computing-you-should-know-about/

[42] W. de Paula Ferreira, F. Armellini, and L. A. De Santa-Eulalia, “Simulation in industry 4.0: A state-of-the-art review,” *Comput Ind Eng*, vol. 149, 2020, doi: 10.1016/j.cie.2020.106868.

[43] B. Rodič, “Industry 4.0 and the New Simulation Modelling Paradigm,” *Organizacija*, vol. 50, no. 3, 2017, doi: 10.1515/orga-2017-0017.

[44] J. C. Sá, J. Dinis-Carvalho, B. Costa, F. J. G. Silva, O. Silva, and V. Lima, “Implementation of Lean Tools in Internal Logistic Improvement,” 2023. doi: 10.4018/978-1-6684-5606-4.ch006.

[45] M. E. H. Korner, M. P. Lambán, J. A. Albajez, J. Santolaria, L. D. C. N. Corrales, and J. Royo, “Systematic literature review: Integration of additive manufacturing and industry 4.0,” *Metals*, vol. 10, no. 8. 2020. doi: 10.3390/met10081061.

[46] J. Butt, “Exploring the interrelationship between additive manufacturing and industry 4.0,” *Designs*, vol. 4, no. 2. 2020. doi: 10.3390/designs4020013.

[47] F. Sherwani, M. M. Asad, and B. S. K. K. Ibrahim, “Collaborative Robots and Industrial Revolution 4.0 (IR 4.0),” in *2020 International Conference on Emerging Trends in Smart Technologies, ICETST 2020*, 2020. doi: 10.1109/ICETST49965.2020.9080724.

[48] M. Humayun, “Industrial Revolution 5.0 and the Role of Cutting Edge Technologies,” *International Journal of Advanced Computer Science and Applications*, vol. 12, no. 12, 2021, doi: 10.14569/IJACSA.2021.0121276.

[49] J. Carmigniani, B. Furht, M. Anisetti, P. Ceravolo, E. Damiani, and M. Ivkovic, “Augmented reality technologies, systems and applications,” *Multimed Tools Appl*, vol. 51, no. 1, 2011, doi: 10.1007/s11042-010-0660-6.

[50] F. De Pace, F. Manuri, and A. Sanna, “Augmented Reality in Industry 4.0,” *American Journal of Computer Science and Information Technology*, vol. 06, no. 01, 2018, doi: 10.21767/2349-3917.100017.

[51] M. Ghobakhloo, “The future of manufacturing industry: a strategic roadmap toward Industry 4.0,” *Journal of Manufacturing Technology Management*, vol. 29, no. 6, 2018, doi: 10.1108/JMTM-02-2018-0057.

[52] L. Thames and D. Schaefer, “Industry 4.0: An Overview of Key Benefits, Technologies, and Challenges,” 2017. doi: 10.1007/978-3-319-50660-9_1.

[53] M. L. Martín-Peña, J. M. Sánchez-López, and E. Díaz-Garrido, “Servitization and digitalization in manufacturing: the influence on firm performance,” *Journal of Business and Industrial Marketing*, vol. 35, no. 3, 2020, doi: 10.1108/JBIM-12-2018-0400.

[54] X. Chen, M. Despeisse, and B. Johansson, “Environmental sustainability of digitalization in manufacturing: A review,” *Sustainability (Switzerland)*, vol. 12, no. 24. 2020. doi: 10.3390/su122410298.

[55] T. D. Oesterreich and F. Teuteberg, “Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry,” *Computers in Industry*, vol. 83. 2016. doi: 10.1016/j.compind.2016.09.006.

[56] “The future of digitalization is now.” Accessed: Jan. 02, 2023. [Online]. Available: https://www.bizzmine.com/en/blog/the-future-of-digitalization-is-now

[57] P. Parviainen, M. Tihinen, J. Kääriäinen, and S. Teppola, “Tackling the digitalization challenge: How to benefit from digitalization in practice,” *International Journal of Information Systems and Project Management*, vol. 5, no. 1, 2017, doi: 10.12821/ijispm050104.

[58] M. S. Pereira, A. Cardoso, J. C. Sá, M. Magalhães, and S. Faria, “Digital Transformation in Organizations and Its Impact on Knowledge Management,” pp. 1–13, Sep. 2022, doi: 10.4018/978-1-6684-5538-8.CH001.

[59] R. Sundar, A. N. Balaji, and R. M. Satheesh Kumar, “A Review on Lean Manufacturing Implementation Techniques,” *Procedia Eng*, vol. 97, pp. 1875–1885, Jan. 2014, doi: 10.1016/J.PROENG.2014.12.341.

[60] J. Bhamu and K. S. Sangwan, “Lean manufacturing: Literature review and research issues,” *International Journal of Operations and Production Management*, vol. 34, no. 7. 2014. doi: 10.1108/IJOPM-08-2012-0315.

[61] P. Hines, M. Holwe, and N. Rich, “Learning to evolve: A review of contemporary lean thinking,” *International Journal of Operations and Production Management*, vol. 24, no. 10. 2004. doi: 10.1108/01443570410558049.

[62] P. Danese, V. Manfè, and P. Romano, “A Systematic Literature Review on Recent Lean Research: State-of-the-art and Future Directions,” *International Journal of Management Reviews*, vol. 20, no. 2, 2018, doi: 10.1111/ijmr.12156.

[63] N. V. K. Jasti and R. Kodali, “A literature review of empirical research methodology in lean manufacturing,” *International Journal of Operations and Production Management*, vol. 34, no. 8. 2014. doi: 10.1108/IJOPM-04-2012-0169.

[64] R. Shah and P. T. Ward, “Lean manufacturing: context, practice bundles, and performance,” *Journal of Operations Management*, vol. 21, no. 2, pp. 129–149, Mar. 2003, doi: 10.1016/S0272-6963(02)00108-0.

[65] J. J. Dahlgaard and S. M. Dahlgaard-Park, “Lean production, six sigma quality, TQM and company culture,” *TQM Magazine*, vol. 18, no. 3, 2006, doi: 10.1108/09544780610659998.

[66] “Lean Thinking and Practice - Lean Enterprise Institute.” Accessed: Jan. 02, 2023. [Online]. Available: https://www.lean.org/lexicon-terms/lean-thinking-and-practice/

[67] A. Chiarini, C. Baccarani, and V. Mascherpa, “Lean production, Toyota Production System and Kaizen philosophy: A conceptual analysis from the perspective of Zen Buddhism,” *TQM Journal*, vol. 30, no. 4, 2018, doi: 10.1108/TQM-12-2017-0178.

[68] Prošic Slobodan, “Kaizen management philosophy,” *International Symposium Engineering Management And Competitiveness*, 2011.

[69] G. Wittenberg, “Kaizen — The many ways of getting better,” *Assembly Automation*, vol. 14, no. 4, 1994, doi: 10.1108/EUM0000000004213.

[70] J. C. Chen, Y. Li, and B. D. Shady, “From value stream mapping toward a lean/sigma continuous improvement process: An industrial case study,” *Int J Prod Res*, vol. 48, no. 4, 2010, doi: 10.1080/00207540802484911.

[71] R. Martins, M. T. Pereira, L. P. Ferreira, J. C. Sá, and F. J. G. Silva, “Warehouse operations logistics improvement in a cork stopper factory,” *Procedia Manuf*, vol. 51, pp. 1723–1729, Jan. 2020, doi: 10.1016/J.PROMFG.2020.10.240.

[72] R. Čiarnienė and M. Vienažindienė, “An Empirical Study of Lean Concept Manifestation,” *Procedia Soc Behav Sci*, vol. 207, pp. 225–233, Oct. 2015, doi: 10.1016/J.SBSPRO.2015.10.091.

[73] M. A. Habib, R. Rizvan, and S. Ahmed, “Implementing lean manufacturing for improvement of operational performance in a labeling and packaging plant: A case study in Bangladesh,” *Results in Engineering*, vol. 17, 2023, doi: 10.1016/j.rineng.2022.100818.

[74] S. Kumar, A. K. Dhingra, and B. Singh, “Kaizen selection for continuous improvement through VSM-Fuzzy-TOPSIS in Small-Scale enterprises: An Indian case study,” *Advances in Fuzzy Systems*, vol. 2018, 2018, doi: 10.1155/2018/2723768.

[75] D. Seth, N. Seth, and P. Dhariwal, “Application of value stream mapping (VSM) for lean and cycle time reduction in complex production environments: a case study,” *Production Planning and Control*, vol. 28, no. 5, 2017, doi: 10.1080/09537287.2017.1300352.

[76] C. Ferreira, J. C. Sá, L. P. Ferreira, M. P. Lopes, T. Pereira, and F. J. G. Silva, “iLeanDMAIC – A methodology for implementing the lean tools,” *Procedia Manuf*, vol. 41, pp. 1095–1102, Jan. 2019, doi: 10.1016/J.PROMFG.2019.10.038.

[77] J. Singh and H. Singh, “Application of lean manufacturing in automotive manufacturing unit,” *International Journal of Lean Six Sigma*, vol. 11, no. 1, 2020, doi: 10.1108/IJLSS-06-2018-0060.

[78] Y. Qin and H. Liu, “Application of Value Stream Mapping in E-Commerce: A Case Study on an Amazon Retailer,” *Sustainability (Switzerland)*, vol. 14, no. 2, 2022, doi: 10.3390/su14020713.

[79] O. Omogbai and K. Salonitis, “The Implementation of 5S Lean Tool Using System Dynamics Approach,” in *Procedia CIRP*, 2017. doi: 10.1016/j.procir.2017.01.057.

[80] S. Roy, K. Kumar, and B. Satpathy, “Strategic planning of optimising productivity: A ‘5S under lean quality’ approach,” in *International Journal of Productivity and Quality Management*, 2021. doi: 10.1504/IJPQM.2021.111994.

[81] B. Chandrayan, A. K. Solanki, and R. Sharma, “Study of 5S lean technique: A review paper,” *International Journal of Productivity and Quality Management*, vol. 26, no. 4, 2019, doi: 10.1504/IJPQM.2019.099625.

[82] “What is 5S? 5S System is explained including tips on getting a 5S program started.” Accessed: Aug. 18, 2023. [Online]. Available: https://www.5stoday.com/what-is-5s/

[83] C. Costa, L. Pinto Ferreira, J. C. Sa, and F. J. G. Silva, “Implementation of 5S Methodology in a Metalworking Company,” 2018. doi: 10.2507/daaam.scibook.2018.01.

[84] S. Singh and K. Kumar, “A study of lean construction and visual management tools through cluster analysis,” *Ain Shams Engineering Journal*, vol. 12, no. 1, 2021, doi: 10.1016/j.asej.2020.04.019.

[85] Y. Eaidgah Torghabehi, A. A. Maki, K. Kurczewski, and A. Abdekhodaee, “Visual management, performance management and continuous improvement: A lean manufacturing approach,” *International Journal of Lean Six Sigma*, vol. 7, no. 2, 2016, doi: 10.1108/IJLSS-09-2014-0028.

[86] S. Kurpjuweit, D. Reinerth, C. G. Schmidt, and S. M. Wagner, “Implementing visual management for continuous improvement: barriers, success factors and best practices,” *Int J Prod Res*, vol. 57, no. 17, 2019, doi: 10.1080/00207543.2018.1553315.

[87] “Visual Management | HoshinCloud.” Accessed: May 15, 2023. [Online]. Available: https://www.hoshinonline.com/visual-management

[88] E. Y. T. Adesta and H. A. Prabowo, “Total Productive Maintenance (TPM) implementation based on lean manufacturing tools in Indonesian manufacturing industries,” *International Journal of Engineering and Technology(UAE)*, vol. 7, no. 3.7 Special Issue 7, 2018, doi: 10.14419/ijet.v7i3.7.16261.

[89] E. Y. T. Adesta, H. A. Prabowo, and D. Agusman, “Evaluating 8 pillars of Total Productive Maintenance (TPM) implementation and their contribution to manufacturing performance,” in *IOP Conference Series: Materials Science and Engineering*, 2018. doi: 10.1088/1757-899X/290/1/012024.

[90] J. Singh and H. Singh, “Justification of TPM pillars for enhancing the performance of manufacturing industry of Northern India,” *International Journal of Productivity and Performance Management*, vol. 69, no. 1, 2020, doi: 10.1108/IJPPM-06-2018-0211.

[91] “Introduction to Lean Manufacturing | Lean Production.” Accessed: May 15, 2023. [Online]. Available: https://www.leanproduction.com/

[92] R. Ahmad and M. S. F. Soberi, “Changeover process improvement based on modified SMED method and other process improvement tools application: an improvement project of 5-axis CNC machine operation in advanced composite manufacturing industry,” *International*

Journal of Advanced Manufacturing Technology, vol. 94, no. 1–4, 2018, doi: 10.1007/s00170-017-0827-7.

[93] D. Stadnicka, "Setup analysis: Combining SMED with other tools," *Management and Production Engineering Review*, vol. 6, no. 1, 2015, doi: 10.1515/mper-2015-0006.

[94] M. Brito, A. L. Ramos, P. Carneiro, and M. A. Gonçalves, "Combining SMED methodology and ergonomics for reduction of setup in a turning production area," *Procedia Manuf*, vol. 13, 2017, doi: 10.1016/j.promfg.2017.09.172.

[95] T. Vieira *et al.*, "Optimization of the cold profiling process through SMED," in *Procedia Manufacturing*, 2019. doi: 10.1016/j.promfg.2020.01.171.

[96] S. Shingō and Productivity Press. Development Team., "Quick changeover for operators : the SMED system," p. 77, 1996, Accessed: Sep. 10, 2023. [Online]. Available: https://books.google.com/books/about/Quick_Changeover_for_Operators.html?hl=pt-PT&id=Nff5qBaGQqQC

[97] A. Silva, J. C. Sá, G. Santos, F. J. G. Silva, L. P. Ferreira, and M. T. Pereira, "A comparison of the application of the smed methodology in two different cutting lines," *Quality Innovation Prosperity*, vol. 25, no. 1, 2021, doi: 10.12776/QIP.V25I1.1446.

[98] "Ferramenta SMED – Kimberly Clark – SOBESI." Accessed: Sep. 10, 2023. [Online]. Available: https://sobesi.wordpress.com/2017/10/10/ferramenta-smed-kimberly-clark/

[99] J. Rodrigues, J. C. V. de Sá, L. P. Ferreira, F. J. G. Silva, and G. Santos, "Lean management 'quick-wins': Results of implementation. A case study," *Quality Innovation Prosperity*, vol. 23, no. 3, pp. 3–21, 2019, doi: 10.12776/QIP.V23I3.1291.

[100] "Gemba Walks for Service Excellence: The Step-by-Step Guide for Identifying ... - Robert Petruska - Google Books." Accessed: Jun. 02, 2023. [Online]. Available: https://books.google.pt/books?hl=en&lr=&id=uxLSBQAAQBAJ&oi=fnd&pg=PP1&dq=gemba+walks&ots=b0pGfoDFqF&sig=P6W5Dj15rH6upQ7XajN1Yrx45YU&redir_esc=y#v=onepage&q=gemba%20walks&f=false

[101] "Gemba Walks the Toyota Way : The Place to Teach and Learn Management - Mohammed Hamed Ahmed Soliman - Google Books." Accessed: Jun. 02, 2023. [Online]. Available: https://books.google.pt/books?hl=en&lr=&id=3g6mEAAAQBAJ&oi=fnd&pg=PP3&dq=gemba+walks&ots=t1DdTfubLU&sig=jnK1YUOE6gr0LO0O-kMG3rcgINc&redir_esc=y#v=onepage&q=gemba%20walks&f=false

[102] D. Romero, P. Gaiardelli, T. Wuest, D. Powell, and M. Thürer, "New Forms of Gemba Walks and Their Digital Tools in the Digital Lean Manufacturing World," in *IFIP Advances in Information and Communication Technology*, 2020. doi: 10.1007/978-3-030-57997-5_50.

[103] J. Dalton, "Gemba Walks," *Great Big Agile*, pp. 173–174, 2019, doi: 10.1007/978-1-4842-4206-3_31.

[104] M. Jesuthasan and D. Owusu, "The Value Proposition for Adopting a Lean Mindset for Utilities," *Climate and Energy*, vol. 37, no. 4, 2020, doi: 10.1002/gas.22198.

APPENDIX A

	JAN	FEV	MAR	ABR	MAI	JUN	JUL	AGO	SET	OUT	YTD 2022
Produção para Outras Áreas Industriais	447 235,79	502 411,02	574 675,04	574 248,68	468 225,52	485 282,44	573 283,69	243 152,56	715 326,52	640 712,01	5 224 553,27
Variação da Produção	- 4 246	- 772	- 6 898	- 10 663	868	1 186	2 669	- 2 340	-	- 10 037	- 30 232
Trabalhos em Curso											-
Total Produção	**442 989,53**	**501 639,17**	**567 776,79**	**563 586,06**	**469 093,66**	**486 468,85**	**575 953,02**	**240 812,53**	**715 326,52**	**630 674,74**	**5 194 320,87**
Consumos de Matérias Primas e Subsidiárias	38 148	2 668	349	47 302	4 194	9 996	13 614	-	43 891	15 610	175 772
Consumos de Outras Áreas Industriais	391 727	474 320	567 825	508 290	444 462	465 346	539 443	233 443	656 923	593 179	4 874 959
Total Consumos	**429 876**	**476 988**	**568 173**	**555 592**	**448 656**	**475 342**	**553 057**	**233 443**	**700 814**	**608 789**	**5 050 731**
Margem Bruta	**13 113,75**	**24 651,24**	**- 396,47**	**7 994,11**	**20 437,19**	**11 126,84**	**22 895,75**	**7 369,30**	**14 512,87**	**21 885,65**	**143 590,23**

Figure 70 - Finacial Results and Costs per month (2022)