Increasing Supply Chain Performance in Digital Society

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Chapter 6
Lean Manufacturing and Industry 4.0/5.0:
Applied Research in the Portuguese Cork Industry

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ABSTRACT

Over the years, organizations have had to adapt to constant changes in their surroundings. To this end, they began to adopt methodologies such as lean manufacturing and Industry 4.0. Their implementation has increased the competitiveness of organizations. Sustainability is getting much attention, leading to the advent of Industry 5.0, which, unlike Industry 4.0, takes sustainable production into account. Forestry sectors are significant for the Portuguese economy, especially cork. This study examines a company in the cork sector to determine how automation and monetization of new resources could increase efficiency, quality, and safety. A qualitative approach was applied in the study through literature review and participant observation actions to analyze and propose improvements. The study fulfilled the purposes defined, identifying options to improve the production process and increase customer satisfaction and worker safety.

INTRODUCTION

The current market is constantly evolving, open to universal competition, and recognized for new technologies and knowledge. Given this fact, administrators are encouraged to optimize all processes in their company, eliminating or reducing waste (Jastia & Kodali, 2015). Several philosophies have emerged

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to accomplish this, including lean manufacturing (LM) or operational optimization, based on Toyota's success; Industry 4.0 (I 4.0), from the internet of things (IoT); big data, 3D printing; cloud computing; artificial intelligence (AI); and cyber-physical systems (Liker, 2004).

Actually, the fifth industrial revolution (I 5.0) is characterized by human-robot cooperation in everyday life and bioeconomy. I 5.0 will increase productivity and operability, reduce workplace accidents, and shorten production processes in a sustainable and environmentally friendly way. It will create jobs, most of them in programming, artificial intelligence, maintenance, training, reuse, and the design of new robots (Demir, Döven, & Sezen, 2019; Nahavandi, 2019).

The present study highlights the interaction between LM and I 4.0/5.0 through a case study in a company in the agroforestry sector, specifically in an industrial cork unit (ICorkU). The forestry and agroforestry sectors are very significant for the Portuguese economy, in which cork exploitation plays a fundamental role. Portugal is the world's largest cork producer and exporter. The Portuguese cork industry is an example of profitable production, with the advantage that the raw material comes from a traditional, environmentally sustainable cultivation system that is well-adapted to the local climate conditions, exemplifying a circular economy (APCOR, 2020).

BACKGROUND

Lean Manufacturing (LM)

According to Drew, McCallum, and Roggenhofer (2004, p.15), lean manufacturing is

a combination of principles, practices, tools, and techniques designed to address the causes of poor operational performance. It is a systematic approach to eliminating losses along a company's value chain to bring current performance closer to customer needs.

The LM production was featured in the book "The machine that changed the world" by Womack et. al. (1990), where they contrasted the difference between the Toyota Production System (TPS) and other automotive companies and concluded that this system made Toyota the most competent organization worldwide in its sector. Figure 1 represents a simplified Toyota Production System (TPS) where there is independence between the concepts, components, people, and practices that apply to the industry and commerce and services.

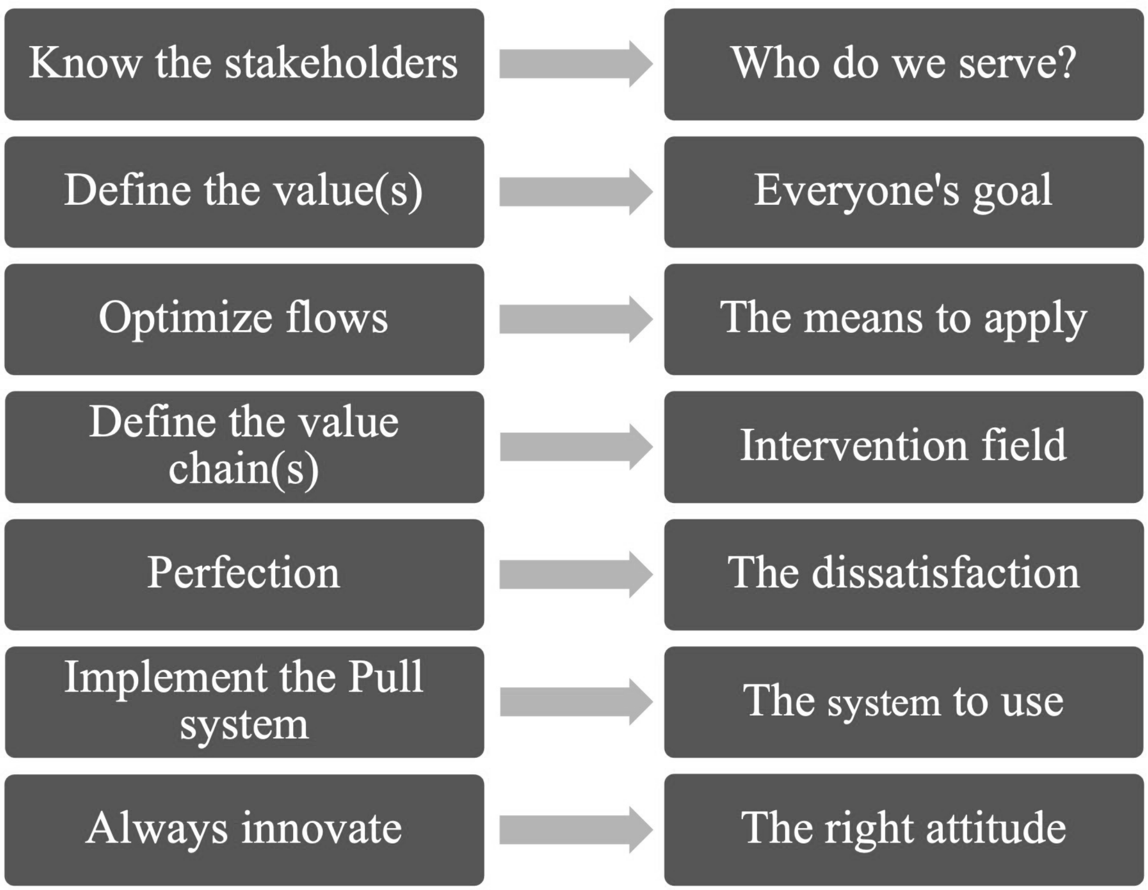
Figure 1. Toyota Production System (TPS) scheme
Source: Liker, 2004

To achieve LM is necessary to understand the manufacturing process and its ultimate goals to rationalize the process and the people involved without creating more unnecessary costs (Womack & Jones, 2004). Markovitz (2011) showed that Toyota is permanently looking to improve its processes, in tune with the LM concept and philosophy directly linked to the development of awareness and learning to eliminate problems, the ability to self-correct, and opportunities for everyone involved to improve, from factory floor people to the top management.

The LM philosophy is a matter of continuity of organizations by the rectification of processes both to minimize costs and to implement best practices, based on getting quality first, continuous process improvement, and problem-solving, is supported by five principles: (i) create value (particularities that a product or service must have and how much the customer is willing to deliver to meet their needs and requirements); (ii) identify the value stream (production process composed only of activities that add value and eliminate non-value-adding activities); (iii) continuous flow (organize all activities to take place continuously and fluidly, without waste); (iv) pull production (start a product or service only when the customer requests, in quantity, and when asked [just-in-time], eliminating exaggerated stocks, increasing productivity and adding value to the product); and (v) pursuing perfection (create opportunities for improvement as new waste and new obstacles arise, with transparent processes in which everyone involved in the value chain has deep knowledge, being able to dialogue and improve the processes) (Davis, 2009; Pinto, 2014; Womack & Jones, 2004).

Pinto (2014) proposed the inclusion of two more principles (Figure 2): Know the stakeholders (know in detail the stakeholders in the process and then eliminate possible existing waste through continuous improvement) and constantly innovate (be based on the constant analysis of stakeholders, constantly evolving, thus achieving a better vision and definition of future goals for companies).

Figure 2. Seven Lean Manufacturing principles
Source: Pinto, 2014



Successful LM implementation is mainly due to its efficiency in reducing the complexity of processes and suppressing process steps that do not create value (Jastia & Kodali, 2015).

LM Tools

LM seeks to create a period of continuous improvement with the help of a wide range of tools which, when well implemented, allows improving the general performance of companies at the operational, financial, human, market, and environmental levels (Gaziero & Cecconello, 2019), as presented in Table 1.

Table 1. LM tools

Tool	Objectives	Authors
SMED (single-minute exchange of die)	It reduces production preparation time and seeks to reduce costs, change, and continuous improvement	Ribeiro et al. (2019); Shingo (1985)
5S (*seiri*, *seiton*, *seiso*, *seiketsu*, *shitsuke*)	It organizes the workplace as its primary function by reducing activities that do not add value to the process 5S five steps: *seiri* (identify and separate tools that are useful or not), *seiton* (organization of valuable tools), *seiso* (maintenance and cleaning of the workplace to simplify the process), *seiketsu* (patterns must be able to maintain the three previous steps), and *shitsuke* (keep the previous steps as a routine, on change the existing behavior	Mayr et al. (2018); Omogbai and Salonitis (2017); Osada (1991)
JIT (just-in-time)	It focuses on producing the necessary quantity for the customer, thus allowing the complete elimination of waste during the process	Ante, Facchini, Mossa, and Digiesi (2018); Hirano (2009); Monden (1993)
Kaizen	It allows the identification and implementation of continuous improvements in the organization, with the help of everyone involved, which aims to constantly improve productivity and quality	Arai and Sekine (1992); Lima, de França Alcantara, Santos, Silva, and Da Silva (2016)
Kanban	It helps identify the location of the material and the order of entry into production. Types of *Kanban*: (i) production – work as authorizations to produce a product, and (ii) transportation – demonstrate the need to transport the product to the production line or warehouse	Buer, Fragapane, and Strandhagen (2018); Hammarberg and Sunden (2014); Strandhagen (2018)
VSM (value stream mapping)	It allows one to visualize and understand all process flows, identify waste, and proceed with its elimination	Duggan and Healey (2016); Gaziero and Cecconello (2019)
Jidoka	"never letting a defect pass to the next stage of the process, but freeing people from the machines" (p. 209)	Liker (2004); Ohno (1988)
Heijunka	It achieves balance and synchronize all operations at a productive level to precisely and flexibly match customer demand	Jones (2006); Liker (2004)
PDCA (plan, do, check, act)	It works as a cycle and represent the path to be followed and the goals achieved at each stage. Set goals and define the methods to achieve them (plan), carry out the planned tasks and collect data for verification in the next step (do), verify and compare data with the intended goals (check), and act in the process based on the data obtained (act)	Shewhart (1931/1980); Werkema (2013)

Industry 4.0 (I 4.0)

The fourth industrial revolution (I 4.0) is characterized by significant convergence and technological advancement. It is already possible to intelligently explore the integration of the physical, biological, and digital worlds (Silva, Scoton, Dias, & Pereira, 2018). The fundamental objective of I 4.0 is to provide the factory floor with more information about consumers and help with real-time production planning, which allows for increased flexibility, productivity, and quality, reducing the production costs and time delivery (Gaziero & Cecconello, 2019).

Fourth Revolution Technologies

Bahrin, Othman, Azli, and Talib et al. (2016) say that the fourth revolution is based on nine technologies (Figure 3). The market is considered “smart” because it allows consumers to participate in the individual personalization of products. The use of new technologies, such as IoT, big data, cyber-physical systems (CPS), sensors and actuators, augmented reality, cybersecurity, electric vehicles, 3D printing, cloud computing, and artificial intelligence (AI), allows the interaction between real-time and virtual and physical worlds, referred to as cyber-physical systems (Nahavandi, 2019).

The main pillars of I 4.0, according to Bahrin et al. (2016), are: internet of things (IoT; physical and virtual objects connected to the internet and the application of sensors to boost wireless communication, permitting the monitoring of performance and making possible decisions at the right time to the correct problems, optimizing available resources); big data (the large amount of data stored at any given moment, originating in information generated by computers, sensors, and other equipment through various formats); and cyber-physical systems (CPS; “intelligent” machines, products, or devices that exchange information autonomously, working in cooperation with the physical world around them).

Figure 3. I 4.0 Technologies
Source: Bahrin et al., 2016

From now on, simulations will be based on real-time data to replicate the physical world in a virtual model, including machines, products, and human beings. In this way, it is possible to test product configurations and machines in a virtual line before moving on to production, that is, to the physical world. It makes it possible to reduce setup times and increase product quality (Bahrin et al., 2016; Gunal, 2019; Luściński & Ivanov, 2020; Xu, Huang, Hsieh, Lee, Jia, & Chen, 2017).

Hozdić (2015) states that I 4.0 is characterized by three dimensions: Vertical integration (connections of people, objects, and systems to create dynamic value networks); horizontal integration (the interaction of different agents through value networks); and end-to-end digital integration (interaction between vertical and horizontal integration, as the collection of product lifecycle information adds value, from its production to the final logistics).

According to Deloitte (2014), I 4.0 can bring numerous benefits, including specific solutions for unique areas, individualized customization, unit batch production, and profit-making; increased competitiveness and flexibility, ability to adapt to value chain changes; obtaining real-time optimization; increased productivity and increased efficiency (more production with the same resources); new employment opportunities and innovative services, among others; more professional balance, flexibility, motivation, and career development; and the possibility of reducing energy and labor costs.

Mixed (Augmented and Virtual) Reality and Artificial Intelligence

Augmented reality (AR) could be defined as (i) enrichment between the real environment with virtual objects, using some technological devices that work in real-time; (ii) improvement of the real world with text, images, and virtual objects with the aid of a computer; (iii) integration of the real and virtual worlds at some points of continuous reality/virtuality, where real environments and virtual environments are linked; and (iv) a system that completes the real world with computer-generated objects, appearing to integrate the same space and combining real and virtual objects in the real environment, interacting in real-time with all the user's senses (Kirner & Siscoutto, 2007).

AR is one of the most used technologies to help professionals in different areas that cannot be present on-site. However, in the future, it can be widely used in real-time, helping in decision-making, and optimizing work procedures (Ikeziri, Melo, Campos, Okimura, & Gobbo Jr., 2020).

Virtual reality (VR) is an advanced user interface to access applications running on a computer, offering the user visualization, movement, and interaction, in real-time, in three-dimensional environments created and managed by a computer. Vision is usually the basis of VR; however, other senses such as touch and hearing can enrich this experience (Kirner & Siscoutto, 2007).

Simulation is fundamental in I 4.0, as it facilitates the assessment of improvements and mirrors the real world through the virtual world. It can help update and improve equipment, layouts, products, and even the positioning of people before approving projects. In this way, it is possible to reduce setup times and increase the quality of processes (Ikeziri et al., 2020).

Industrial applications of artificial intelligence (AI) can be defined as the simulation of intelligence like the human brain, capable of autonomously controlling and making decisions about industrial processes, physical operations, or systems. Industrial AI includes product manufacturing, supply chains, and warehouse management, among many others (Bécue, Praça, & Gama, 2021).

The Interaction of Lean Manufacturing With Industry 4.0

Kolberg and Zühlke (2015) identified some flaws in the interaction of LM with I4.0, which highlights the lack of a framework to help integrate manual and automated workstations. Standardization, organization, and transparency of work are LM concepts highlighted as support for implementing I4.0 solutions.

Sanders, Elangeswaran, and Wulfsberg (2016) concluded that I4.0 is, in fact, efficient to help implement the concept of LM in companies. They analyzed existing barriers to its implementation and alternative conceptual proposals for solving these problems, verifying that I4.0 allows the company to increase its productivity and reduce waste, a LM principle.

Interoperability between LM and I4.0 occurs at the operational and sociotechnical levels. At the operational level, it is possible to observe vertical and horizontal integration existing in the production process through the integration of LM and I4.0 tools and principles. Sociotechnical factors are based on the complex interaction between people, machines, and environmental aspects of organizational strategies. The most significant complexity happens with the increase of this interaction and the way people accept the changes at each corporate level (Davies et al., 2017).

The application of I4.0 technologies to LM methods generates lean automation, a concept that points to the inclusion of the best practices of both models. An example of this harmony is the addition of modern information and communications technologies (ICTs) in the *kanban* method, improving efficiency (Ikeziri et al., 2020).

Several authors have described the dimensions of LM management and how the concepts and technologies of I4.0 manage to simplify its application. Table 2 presents the possible scenarios of results.

Table 2. Possible interactions between LM and I4.0 (Sanders et al., 2016)

LM Objectives	LM Implementation Challenge for I4.0	Solutions obtained through I4.0
Suppliers' opinion	Limited knowledge and staff	Collaborative manufacturing
	Different types of businesses, operations, and maintenance	Data synchronization
		Better communication mechanisms
JIT deliveries made by suppliers	Delays during transport	Smart order reallocation
	Poor quality of transported items	Wireless tracking of goods
Supplier developments	Inadequate resources and knowledge	Standardized interfaces
	Equipment compatibility between companies	Virtual organizations synergistic cooperation
Customer involvement	Low flexibility for product change	Extended freezing period
	Relationship between function and need	Implementation of the quality function deployment (QFD) in large volumes
	Get exact quantities from customers	Usage analysis
Pulled production	Improper quantity of material supplied	Material tracking monitoring
	Changing the production schedule	Tracking and updating the production schedule, and *kanban*
Continuous flow	Errors in stock counts	Real-time stock tracking
	Lack of capacity	Subcontracting
	Centralized control systems	Decentralized decision making

Continued on following page

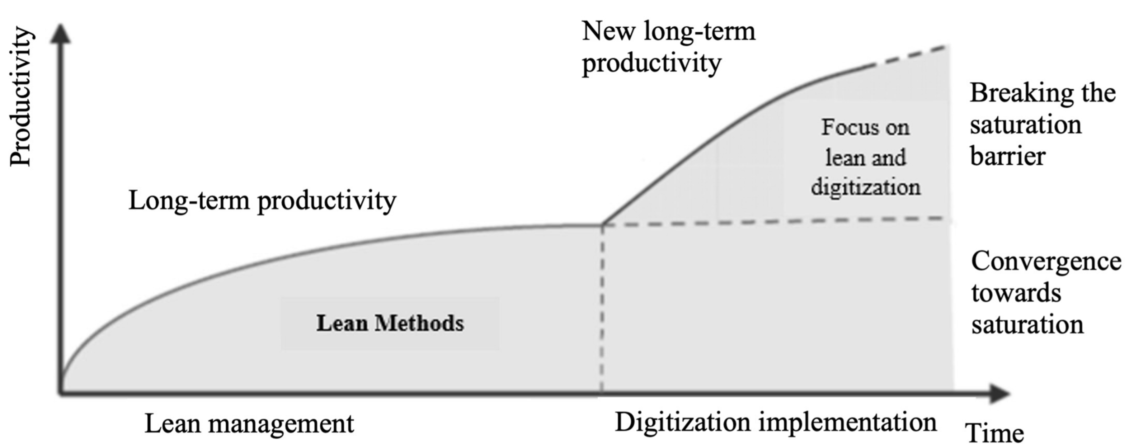
Table 2. Continued

LM Objectives	LM Implementation Challenge for I4.0	Solutions obtained through I4.0
Setup time reduction	System adaptation based on human experience	Communication between parts and machines
		Self-optimization and machine tuning
Preventive maintenance / Total productive	No control over machine breakdowns	Machine worker communication
	"New" problem-solving time	Automated maintenance assessment
		Predictive maintenance control systems
Statistical process control	Lack of knowledge of operators	Communication between machines and people
	Inability to track process variations	Better human-machine communication
		Tracking in the integral of processes
Worker involvement	Incorrect communication mechanisms	Smart communication devices
	Performance appraisal practices	Employee support systems
	Work monotony	Better human-machine communication

Prinz, Kreggenfeld, and Kuhlenkötter (2018) studied a factory to prepare workers for the new reality resulting from I4.0. Various production line operations and failures already had the LM tools implemented and simulated to solve problems and improve the current system. Thus, they had to use digitization as a resource to obtain real-time information and assistance, using elements such as CPS and IoT, that is, tools from I4.0. The main objective was to make clear the benefits of LM and I4.0.

However, for a successful implementation of digitization, the production process must be optimized and organized based on LM principles. In this way, companies ensure more effective use of resources, achieving the processes and production flow standardization transparently, increasing productivity. They proved that organizations with a solid LM system benefit from implementing I4.0 through more extraordinary operational performance, as shown in Figure 4.

Figure 4. Productivity curve between LM and I4.0
Source: Prinz et al. (2018)



Based on the available literature, LM thinking simplifies the implementation of I4.0, but it is recognized that it is necessary to make a high investment in digitizing the production process. However, this investment will not pay off if it cannot improve the existing process and has much waste. LM thinking helps implement I4.0, as it streamlines operations, permanently eliminates waste, and clarifies processes and work planning (Bittencourt, Alves, & Leão, 2019).

Rosin, Forget, Lamouri, and Pellerin (2019) found excellent support of I4.0 in just-in-time and *jidoka* concepts and substantial help from IoT and simulation in LM technologies. However, several authors found that I4.0 technologies cannot fully integrate LM principles, but they strengthen its efficiency. Thus, there is a clear need to progress in the implementation of LM management and, at the same time, improve its principles, using technologies that are in line with the possibilities. I4.0, IoT, and CPS demonstrate more harmony with LM practices and more financial return in a short period. So, these technologies are suggested for starting the transition instead of an advanced robotization, as they present less complexity (Pagliosa, Tortorella, & Ferreira, 2019). Digitization processes in companies can be costly and challenging at an early stage, but they lead to improved competitiveness in the long term. Developments in digitalization have proven to be a feasible commercial strategy for the continuity of companies in different sectors (Ghobakhloo & Fathi, 2020).

Lean Manufacturing & Industry 4.0 tools

The LM related to I4.0 tools are, among others, *kanban, heijunka, kaizen*, just-in-time (JIT), standardized work, and *jidoka* (Ikeziri et al., 2020). Several researchers are analyzing the benefits of technologies for (i) the visual management of production and logistics flows; (ii) production leveling; (iii) continuous improvement; (iv) acquisition of materials only in the quantities needed and when necessary (JIT); (v) reduction in production instability; (vi) simplification of the training process for employees; (vii) reinforcement of operational security; (viii) documentation simplicity; and (ix) synergy between automation and technologies that monitor product quality without the help of employees (Ejsmont, Gladysz, Corti, Castaño, Mohammed, & Martinez Lastra, 2020). Table 3 presents the LM tools and their interaction with I4.0 technologies.

Table 3. LM tools and their direct interaction with I4.0 technologies (Ejsmont et al., 2020; Pagliosa et al., 2019)

LM tools	I4.0 technologies
Kanban	Horizontal integration; cloud computing; simulation
Heijunka	Horizontal integration; simulation; vertical integration; big data; sensors and actuators; cloud computing
Kaizen	Horizontal integration; simulation; vertical integration; big data; sensors and actuators; cloud computing; augmented reality (AR); virtual reality (VR)
Just-in-time	Horizontal integration; simulation; vertical integration; big data; AR; sensors and actuators; cloud computing; RFID
Standardized work	Horizontal Integration; simulation; vertical integration; big data; sensors and actuators; cloud computing; AR; VR
Jidoka	Horizontal integration; simulation; vertical integration; big data; cloud computing
Waste reduction	Horizontal integration; simulation; vertical integration; big data; IoT
People management and teamwork	Simulation; big data; AR; VR
Pulled production (pull)	Horizontal integration; vertical integration; sensors and actuators; IoT
Suppliers and customers management (stakeholders)	Horizontal integration; big data; cloud computing; IoT
VSM	Horizontal integration; big data; simulation; RFID
Visual management	IoT; big data; simulation; AR; RFID
SMED	Additive manufacturing (3D printing); AR
5S	AR; VR
Continuous flow	RFID; IoT; simulation
TPM	Simulation; big data; AR; VR
SMED, *Kaizen*, *Heijunka*	Simulation
VSM, Standardized work	Horizontal integration; vertical integration
5S, Standardized work	Sensors and actuators

I4.0 technologies that stand out in the LM tools interaction are (i) horizontal integration (helps manage the entire production chain with the aim of allow everyone to achieve the company's goals); (ii) vertical integration (make it possible to visualize the efficiency of all LM elements in the company's production process); (iii) big data (aggregates all historical and current data, allowing for its analysis and demonstrating its value in the daily lives of companies); (iv) augmented & virtual reality (certifies I4.0 with the productive processes implemented in companies); (v) sensors and actuators (data collection sources to be archived in big data and examined in simulations, such as leveling production); (vi) cloud computing (closely related to all LM concepts, confirming its widespread use, given its capabilities are increasing in systems and infrastructure); and (vii) simulation (linked to training activities and the use of test scenarios without interfering with the current reality, thus managing to avoid unnecessary expenses and helping to predict future situations (Bahrin et al., 2016; Hozdić, 2015; Ikeziri et al., 2020; Nahavandi, 2019; Pinto, 2020). Table 4 presents the I4.0 technologies and their interaction with LM tools.

Table 4. I4.0 technologies and their direct interaction with LM tools (Ejsmont et al., 2020; Pagliosa et al., 2019)

I 4.0 technologies	LM tools
Horizontal integration	*Kanban; heijunka; kaizen; just-in-time;* standardized work*; jidoka;* waste reduction, pull production*;* suppliers and customers management (stakeholders)
Vertical integration	*Heijunka; kaizen;* just-in-time; standardized work*; jidoka;* waste reduction*;* pulled production
Big data	*Heijunka; kaizen;* just-in-time; standardized work; *jidoka;* waste reduction;
Augmented reality	*Kaizen;* just-in-time; standardized work; people management & teamwork; 5S
Virtual reality	*Heijunka; kaizen;* standardized work; people management & teamwork; 5S
Sensors and actuators	*Heijunka;* just-in-time; standardized work, pulled production; 5S
Cloud computing	*Kanban; heijunka; kaizen;* just-in-time; standardized work; *jidoka*
Simulation	*Heijunka; kaizen;* just-in-time; standardized work*; jidoka;* waste reduction; people management & teamwork; 5S
IoT	Waste reduction, pull production; visual management on the workstation
Big data + simulation	People management & teamwork; management of suppliers and customers (stakeholders); visual management
Horizontal integration + vertical integration	VSM + standardized work
Simulation + IoT	Continuous flow
Cloud computing + IoT	*Jidoka*

The integrated implementation of LM and I4.0 can improve company results (Tortorella, Narayanamurthy, & Thurer, 2021).

Industry 5.0 (I5.0)

While the most recent advances reduced human intervention in the production process, I5.0 translates into a human-machine symbiosis aiming to improve the production process in real-time, called customizable autonomous production. The focus of I4.0 does not include sustainability, so I 5.0 will also consider protecting the environment, promoting sustainable production (Nahavandi, 2019). Currently, there are two visions for the I5.0. One highlights the human-robot symbiosis, where both will work together whenever possible, with humans assigned to the most complex creativity activities and robots the remaining tasks. The other vision highlights the bioeconomy, where biological resources for industrial purposes will balance the environment, industry, and economy.

According to the European Commission, the bioeconomy is the production using renewable biological materials and the conversion of waste into products that add value, for example, food, feed, bio-based products, and bioenergy. These resources highlight agriculture, forestry, fishing, food, and the production of pulp and paper and parts of the chemical, biotechnology, and energy industries. In combination, these factors can participate in or be the lever for the next industrial revolution (Demir et al. 2019). Table 5 presents the comparison of the vision of I4.0 and I5.0.

Table 5. I4.0 and I5.0 vision comparison (Demir et al., 2019)

	I4.0	I5.0 (v. 1)	I5.0 (v. 2)
Concept	Smart production	Human-robot symbiosis	Bioeconomy
Motivation	Mass production	Smart society	Sustainability
Power supply	Electricity Fossil-based fuels Renewable energy sources	Renewable energy sources electricity	Electricity Renewable energy sources
Technologies	Cloud computing using IoT Big data Robotics and AI	Human-robot collaboration Renewable resources	Agriculture and sustainable production Renewable resources
Involved areas	Process improvement and innovation Business administration	Smart environments Process improvement and innovation Business administration	Agriculture Biology Waste Business administration Economy

I5.0 will be a significant change for organizations, whether the work is done in conjunction with humans and robots or not. Probably the most significant change is the involvement of robots in everyday life, as their progress meets human characteristics. This evolution and cooperation raise legal, psychological, social, ethical, and regulatory issues. Issues of collaboration or competition between humans and robots will emerge, with possible negative attitudes on cooperation and acceptance (Demir et al., 2019).

It is necessary to reduce the costs of robots without reducing their capacity, efficiency, and safety. I5.0 will increase productivity and operability, reduce workplace accidents, and shorten production processes in a sustainable and environmentally friendly way. Contrary to expectations, I5.0 will create jobs, mainly in programming, artificial intelligence, maintenance, training, reuse, and the design of new robots (Nahavandi, 2019).

Several studies demonstrate that the main difference from I4.0 to I5.0 is the shift from intelligent production to intelligent consumption. While I4.0 focuses on production, I5.0 focuses on time and experiences while consuming the product (Rosemann et al., 2021). I5.0 has been based on 6R methodology and logistics efficiency design (LED) principles, leading to occasional comparisons with the circular economy.

The 6R methodology comprises: (i) reduce (identify the origin of the waste and that one with more significance in process, and seek to reduce it); (ii) reuse (find alternatives for the residues of the production process); (iii) recycle (look for a destination for the waste produced; (iv) rethink (identify the waste sources and the method to safely dispose of it, taking into account best environmental practices); (v) recover (recover the waste and send it to another industry that can recycle it); and (vi) refuse (refuse to produce waste and try to find alternatives (Mekkunnel, 2019).

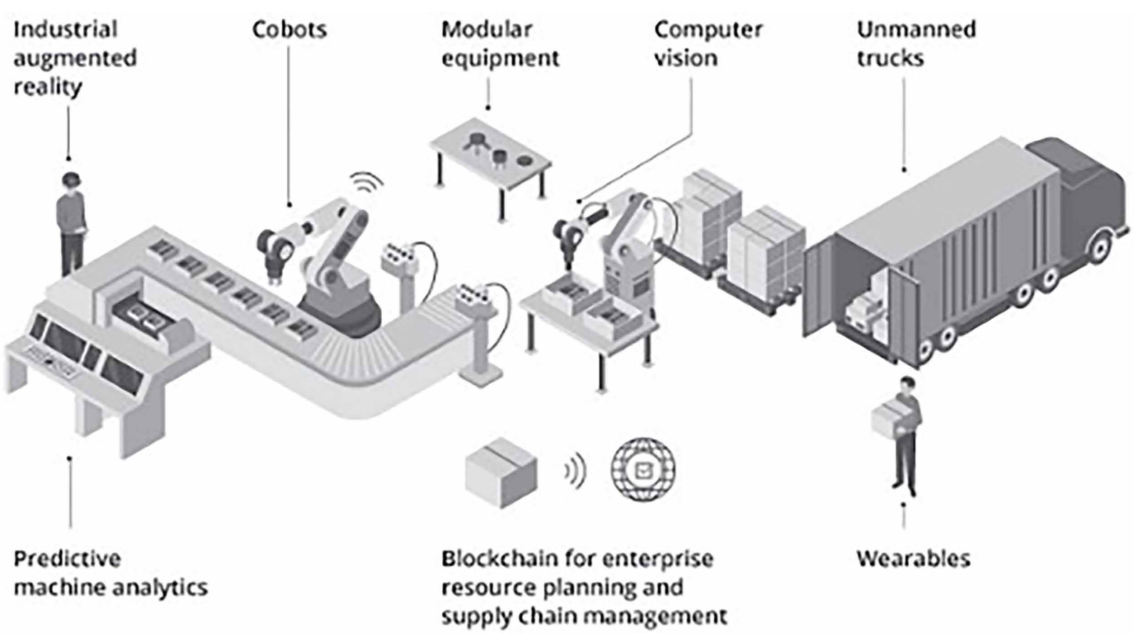
The primary objective of LED is to improve the supply chain's efficiency by eliminating waste generated in the current process (Peraković, Periša, Cvitić, & Zorić, 2020). One of the technologies supported by I5.0 is robotic process automation (RPA), which consists of robotic software that allows users to collect and analyze user interactions and verify the actions of devices in the various production processes (Mekkunnel, 2019).

Companies can improve the production area through adaptability (automation allows organizations to direct personnel to different departments, removing them from unsafe areas, increasing the organization's competitiveness); security and protection (reduction of concern about problems due to interruptions in the production process with the improvement of cybernetic resources); control and clarity (precise, reliable, and current [real-time] production processes and their availability in a short period); customer satisfaction (helps the factory interact with the customer, optimizing time and creating collaborative production opportunities between manufacturers and industries globally); and customization (reaching new markets with 3D printers helps quickly produce specific products and with smaller-scale productions) (Mekkunnel, 2019).

The synergy between humans and the technology in I5.0 will affect the economy, the ecology, and the social world, being accompanied by an aspect of waste prevention applied in industrial recycling, which can be physical waste (produced by the production and logistics lines; also includes general common waste); urban waste (unnecessary spaces, empty spaces, inadequate infrastructure); process residues (overproductions, empty trucks in circulation, excess stock); and social waste (people who want to work but do not have the opportunity; this also includes people who do not want to work). These four types of waste significantly impact the economy and the environment in reducing wasted materials and resources since manufacturers are focused on reducing material costs and reducing the social impact on their production processes (Paschek, Mocan, & Draghici, 2019).

One of the biggest challenges will be human-machine interaction, where robots will no longer be independent in the automation process but will become partners. In I5.0, the new generation of robots will be called Cobots. Their main functionality of quick understanding and memory will also deal with safety criteria and processes related to the risks inherent in the work. Cobots will also oversee repetitive and heavy work. Meanwhile, people will adapt the product or service to the end consumer's needs (Peraković et al., 2020).

Figure 5. I5.0 factory example (Peraković et al., 2020)



In I5.0, a large amount of information collected through sensors in manufacturing facilities (in physical space) accumulates in cyberspace, where artificial intelligence (AI) analyzes it. The results of that analysis are returned to users in the field in various ways. This process adds new value to the production process in the value chain of delivering the final product or service that allows the provision of products or services tailored to the different individual needs of users. In the industry, big data analysis includes various types of information, including supplier stocks, delivery times for the final product or service, demand for products, or final service (Peraković et al., 2020).

Rosemann et al. (2021, p.123) state that I5.0 would impact another macro-organization, the city, defined as "a livable city that is (re)modeled to eliminate restrictions to its citizens, using digitization to supply goods and public services". An unrestricted city would be an ideal state that can never be reached. The City 5.0 context provides a vital goal expected to drive innovation and improve quality of life. This notion facilitates the transition of the city's environments, focusing on facilitating unrestricted free access to public goods and services.

METHODOLOGY

The general objective of the present study is to: Study the interaction between LM and I4.0/5.0 in an ICorkU and demonstrate that technological investment can result in lower labor dependence and higher production efficiency and quality.

The specific objectives are: (i) analyze the advantages of the interaction between LM and I4.0; (ii) understand the tools' evolution and interactions; (iii) explore the LM and I4.0 tools to be applied in the case study; and (iv) identify I5.0 concepts and tools to be applied in the case study.

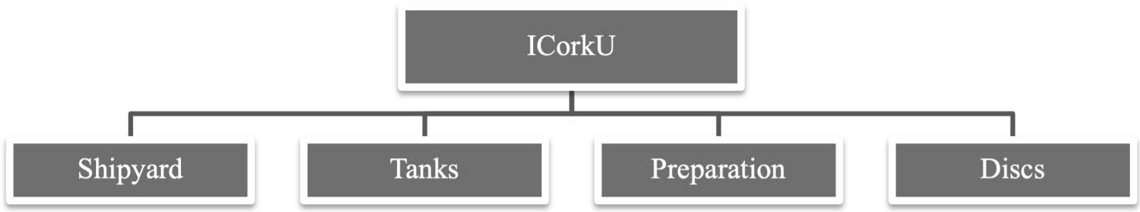
The literature review made possible to obtain the necessary conceptual framework to be complemented with research / field work in the company, thus developing an empirical investigation in a cork sector organization.

The methodology was adapted to the company's processes and operations specificity, object of the study, focusing on the use of direct and participant observation. So, this research study follows an applied nature, with descriptive and explanatory objectives, in a qualitative approach using technical procedures: bibliographic, document analysis, and survey, through participant observation to collect and analyze data and propose improvements, in a participatory and cooperative way, characteristic of the action-research technique (Campenhoudt, Marquet, & Quivy, 2019).

Industrial Cork Unit

The industrial cork unit (ICorkU), the case study object, is dedicated to the reception and processing of raw materials and is divided into four sections, as shown in Figure 6.

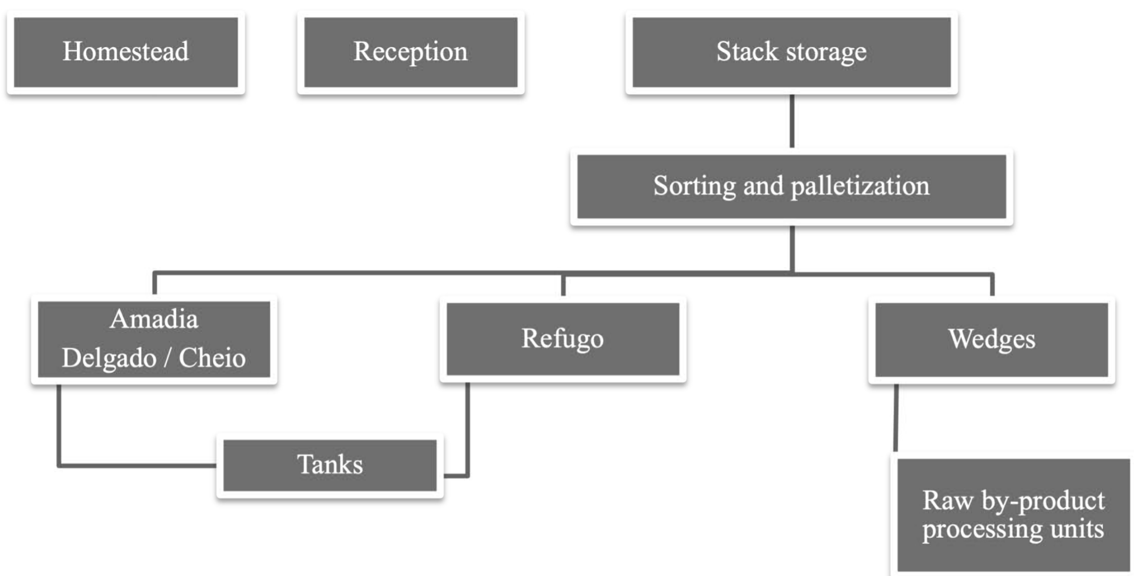
Figure 6. Diagram of the ICorkU sections



The shipyard section receives and stores the raw material, in this case, cork. It also gets the by-products inherent to its extraction, subsequently selling it to natural by-product processing units (customers). The cork storage and stabilization period are at least six months so that the cork can lose its "greenness", i.e., the excess water. Stabilization can reach a maximum of two years since sensory problems may arise in the raw material after this period. After this stabilization period, the first qualitative sorting process is carried out for two alternatives: *refugo* (low utilization cork) and *amadia* (*delgado* and *cheio* cork) (Note: *refugo*, *delgado*, *cheio* and *amadia* are Portuguese terms for cork selection).

In this selection process, main by-products are removed, such as the wedges found in the part of the corkboard directly in contact with the earth. These by-products remain at the shipyard until they are sold in bulk to various natural by-product processing customers. Figure 7 schematically illustrates the shipyard section processes.

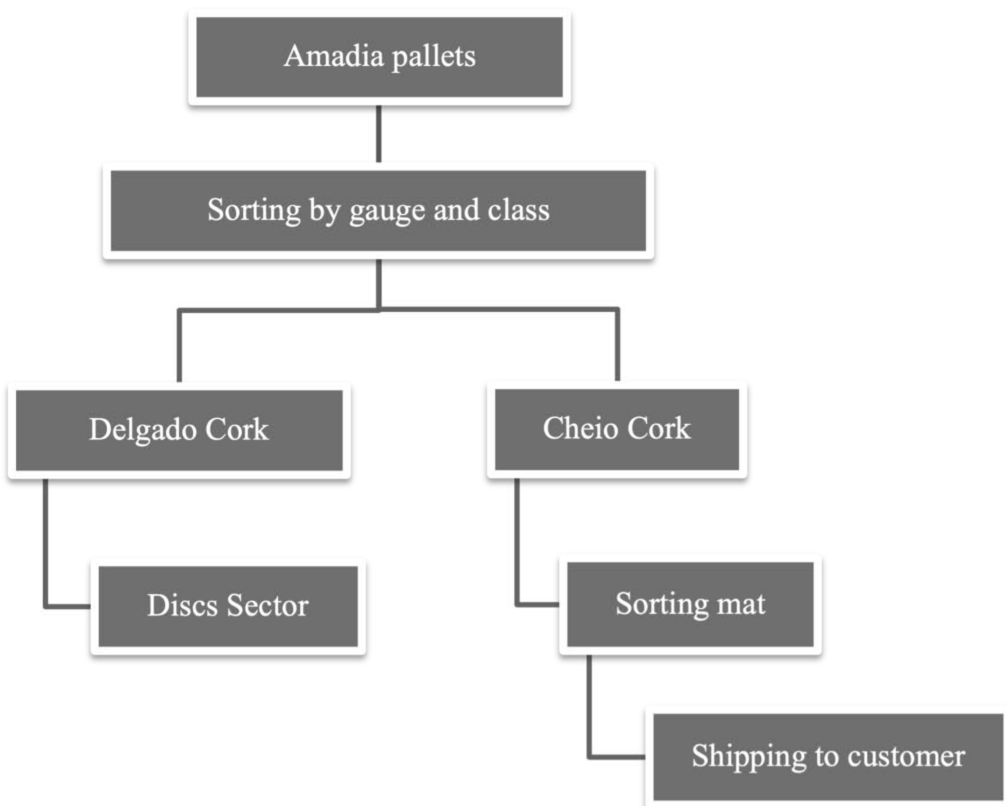
Figure 7. Shipyard section processes diagram



From this process, cork leaves pallets and goes to the tanks section. The cork pallets resulting from the shipyard's first sorting process are cooked in tanks for one hour at 98°C to make the cork malleable for the subsequent manufacturing processes. That cleans the cork of dust and dirt, TCA (trichloroanisole), and other sensory problems such as mold, restoring the natural cork's moisture water renewed each time it is cooked. The *refugo* is boiled and sent to customers (processing units for cooked by-products).

The preparation section is where the *amadia* pallets, coming from the tanks section are subject to a corkboard sorting process between *delgado* (low thickness) and *cheio* (high thickness). Figure 8 presents the preparation section processes.

Figure 8. Preparation section processes diagram



Cheio corkboards are subject to a process of selection by gauge and class, in a very traditional way where the sorting is made with the aid of a "line foot" for the selection of gauge. The sorting by class is performed with the naked eye based on workers' knowledge and later palletized to be sent to an industrial cork stopper unit, where it will be transformed into natural cork stoppers.

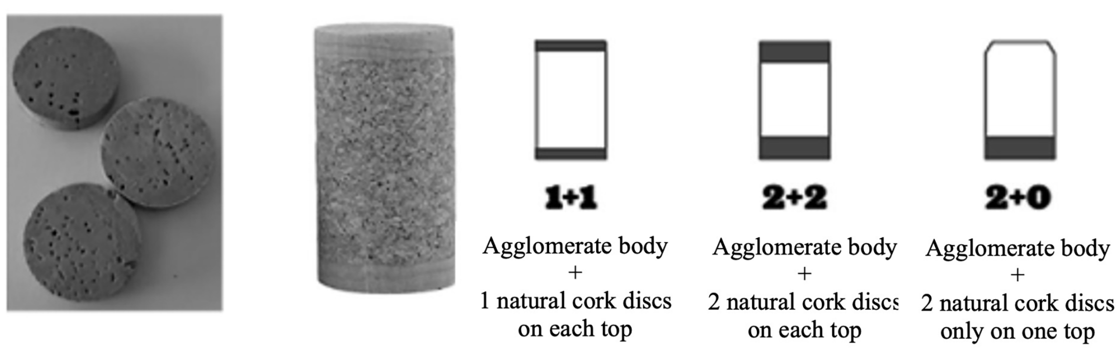
The *delgado* corkboards are also processed and subjected to a traditional process of sorting in gauge and class where the worker is the key person; these are also palletized and later sent to the discs section, where they undergo a cork disc manufacturing process, resulting in thousands of discs and by-products.

The discs undergo a process of rectification and an electronic selection by classes to be applied in champagne or wine stoppers. Figure 9 shows 34.5mm discs and Champagne stoppers.

Figure 9. 34.5mm discs and Champagne stoppers
Source: Industrial cork unit

Discs that fail to reach the dimensions or characteristics required for Champagne stoppers are disqualified and sent to the cork disc customer to be used as wine stoppers. Figure 10 shows wine stoppers and 26.5 mm natural cork discs.

Figure 10. 26.5mm discs and wine stoppers
Source: Industrial cork unit



The by-products are sent to customers in the granulate area to be applied to other cork products.

CASE STUDY

Cork Selection Processes

Shipyard Section—Previous & Actual Situations, Comparison of the Two Realities

As shown in Figure 7 before, the previous first sorting process carried out at the shipyard section identifies three alternatives: *refugo* (low-use cork), *delgado* (thin cork), and *cheio* (thick cork). During this process, by-products called wedges are identified and removed. Three workers are needed for the first sorting: two for sorting, and one for palletizing the corkboards. The wedges are loaded into storage bins and transported to the raw by-products storage location, where they will later be loaded in bulk to by-product processing units (customer).

In the selection process, workers remove the corkboards from stacks and evaluate them, cutting the corkboard's end to remove the wedges. Corkboards are then separated by *delgado* and *cheio* and placed in a line-up on each pallet. The *delgado* and *cheio* pallets go on to the cooking process in the tanks section.

The entire first sorting process carried out at the shipyard section must be quantified and registered in the computer system. Given the section's size, it is impossible to make this record directly in the system, so manual records are kept. These records contain information on the number of kilograms worked and how many pallets were made by each team. It is thus possible to know how many people are needed to achieve the section's objectives. For example, around 25 people are needed to work 60,000 kg of cork, handling an average of 2,400 kg per day for the sorting and palletizing processes. In the actual first sorting process, teams are made up of two workers to sort and palletize simultaneously instead of the previous three. The process starts with the worker removing the corkboard from a pile, identifying the by-products, cutting them with the help of a cutting machine, and placing them in a cage and palletizing the remaining corkboard. *Refugo* and *amadia* (*delgado* and *cheio*) are now on pallets for the cooking process, carried out in the tanks section. After the cooking process the *amadia* go to the preparation section to be submitted to a second sorting. *Refugo* remains in a routing circuit to units for the processing of cooked by-products.

With this new type of sorting, there is greater profitability, and it is possible to reduce the number of workers. For example, for the same 60,000 kg of cork, it takes about 15 people (10 fewer) to make an average of 2,500 kg per day (plus 100 kg).

Daily meetings are held with the staff at the beginning of each working day. The lack of information/knowledge observed about the importance of the process led to a weekly meeting to disseminate each team's daily planning, production data, the section's total, and the objectives and goals to be achieved. This action led to greater involvement of all stakeholders, with greater focus and significant intervention, helping to make a more detailed survey of all actions/activities developed in the processes, especially those that did not add value.

All the improvements obtained, currently or in the future, aim to continuously improve productivity and quality for all interested parties in these processes. Several solutions were developed in response to the detected problems to increase the flexibility of the selection and palletizing processes and make the system more efficient.

From the perspective of LM principles, the survey of existing processes allowed the identification of existing waste, for example, excessive processing or actions/activities developed that did not add value to the product.

The *kaizen* tool helps in exchanging information between all parties, which allows identifying and carrying out a detailed value flow mapping to detect and eliminate unnecessary processes and implement continuous improvement actions in the quality area and productivity.

The PDCA proves to be an asset in this process by setting goals and analyzing processes to be achieved. In carrying out the tasks, it is necessary to involve the workers, and for this, the necessary information was provided, and their training developed. Finally, the verification of results and actions is carried out given the established goals. Table 6 presents the shipyard section comparison of the two realities (previous and actual) and the improvements (obtained and future).

Table 6. Comparison of the two realities (previous and actual) and improvements in the shipyard section

Shipyard Section—*Cork first sorting*				
#	**Previous reality**	**Actual reality with LM & I 4.0/5.0**	**Obtained improvements**	**Future improvements**
1	3 Alternatives (*refugo, delgado,* and *cheio*)	2 Alternatives (*refugo* and *amadia*)	Fewer classes, less complexity, minor specialization	
2	3 workers (2 on sorting and 1 on palletization)	2 workers who carry out sorting, and palletizing	Reduction of 1 worker	
3	Repetitive movements (pick up corkboards from the floor)	Workers sort and palletize (placement of the board logo on the pallet)	Minor discomfort for workers, less absenteeism	
4	Ignorance of the intended planning, objectives, and goals	Planning information, objectives, and goals to be achieved	More information, involvement of all employees in the processes	
5	Weighing, production, and team registration carried out on paper	Weighing, production, and registration of the team carried out on paper		Tablet implementation on machines for computerized registration, reducing repetitive work, and margin of error
6	Fixed scale weighing	Fixed scale weighing		Implementation of scales on machines directly connected to the tablet, real-time information, and no margin for error

Preparation Section—Previous and Actual Situations, Comparison of the Two Realities

There is a worker per bench in the preparation section second selection process, surrounded by cages to sort the corkboards by gauge and class. In this process, the worker must also sort the corkboards by defects. The *delgado* pallets are divided into 6/8 gauges (which go to the discs production line with one blade; the cork is thin, so you can only get a strip of the board to produce the cork discs), and 8/12 (which go to the discs production line with two or three blades; the greater thickness of the cork makes it possible to obtain more strips from the initial board and, thus, be more profitable by producing more discs).

In the second sorting process, the *cheio* cork pallets arrive at the worker's bench, and the worker has to trace one of the ends, which helps him decide on the cork gauge, having to look/observe three aspects: belly, the inner part of the corkboard (which is in contact with the tree trunk); back, the outer part of the corkboard (which is in contact with the environment, dark part of the cork); and mass of the board, cells that, when developing, give thickness to the corkboard. The gauge standards are shown in Figure 11 (a). The *cheio* part is divided into 12/14, 13/15, 15/20, and 18/24 gauges. For example, the 12/14 gauge has a thickness between 27 and 32 mm, and its division varies the size and length of the cork stopper that customers produce. In addition, it is necessary to analyze each corkboard's class, as shown in Figure 11 (b), as these are the two processes with the highest degree of complexity in this phase.

Figure 11. Cheio gauge and class pattern
Source: Industrial cork unit

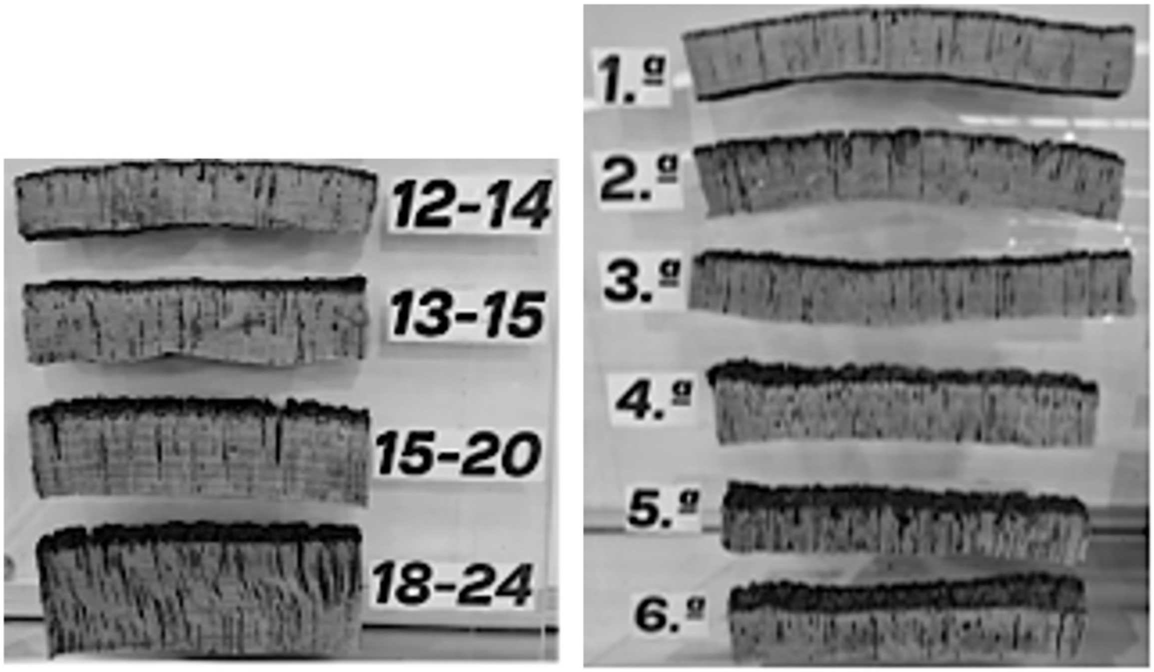


Figure 12 (a) shows the cork sorting bench, where the corkboard cut form and the cages (storage box with wheels) around the worker can be seen. After the entire selection process, the worker places the boards in the corresponding cage, identified by gauge and class, as shown in Figure 12 (b).

Figure 12. Cork sorting bench and cages
Source: Industrial cork unit

The entire selection process must be registered and quantified, which is done by the forklift operator through a tablet available on the equipment and with the TrakSYS platform, which collects and stores, in real-time, all the information of the production process, from the entry of raw material to the output of the finished product. The input data are the weight of each pallet placed on the bench, batch (source of raw material – Company lands), and identification of the worker who will carry out the work.

Suppose there are unfinished pallets and cages at the end of the workday. In that case, the cages are all weighed to obtain production indicators, in real-time, based on the number of kilograms worked during the day and the quantity for each worker. It is essential to know if all workers have similar productivity and are following the general section objective. If not verified, it becomes necessary to understand the worker's needs or existing difficulties. For example, if the section aims to work 50,208 kg of cork, to achieve this goal, it needs 24 people to trace (cut the end of the corkboard) and sort the cork; that is, each worker must be able to work an average of 2,092 kg.

Actually, the *amadia* pallets are placed on the pallet structures so that workers at the beginning of the sorting line can again make a second sorting, where the *delgado* will be removed and separated by gauge but not by class; that is, it goes as 6/8 and 8/12 directly to the discs section. Then, the workers place the corkboards entirely on the mat to pass through a portico system that makes the laser reading of the cork gauge (12/14, 13/15, 15/20, and 18/24). Figure 13 shows the portico's system circuit.

Figure 13. Circuit of the portico system
Source: Industrial cork unit

At the end of each mat, there is a worker to sort and classify each corkboard by class, initially analyzing its coast, belly, and mass and, later, the class, in a similar way to the previous process, where the sorting is made mainly based on the worker's knowledge. According to the customer's needs, there are open classes groups, such as 1st/4th or fifth/sixth, to guarantee the stoppers production with the wanted customer's diameter and length. For example, in gauge 18/24 [see Figure 11 (a)], the 1st/6th class [see Figure 11 (b)] is used, as this is a very peculiar cork in terms of thickness and density, being specific for a particular type of stopper.

In this selection process, the worker will trace each corkboard (cut off the end of the corkboard, to check the quality, that is, the grade) and place it on the pallet with the help of a metal structure that helps the alignment of the corkboard to be shipped to the customer, as shown in Figure 14.

Figure 14. Metal structure to finish the cork pallet
Source: Industrial cork unit

All pallets entering the beginning of the line are weighed, and all pallets and cages resulting from the class selection process are registered on the TrakSYS platform. In addition, a laser sorting machine provides information on the number of kilograms per gauge that passes through the portico. This information is manually registered later on the TrakSYS platform.

The need to understand whether all workers have homogeneous productivity and are following the general objective of the section remains, as in the previous process. For example, if the section aims to work 50,540 kg of cork, to achieve this goal, it will need 20 people to trace and sort, now only per class; that is, each worker should be able to work an average of 2,527 kg.

In the preparation section, the second sorting process requires workers with knowledge about the raw material obtained during their stay in the shipyard section to acquire sufficient experience to make an appropriate gauge cork sorting. Due to the complex raw material sorting, the acquisition of the automatic sorting portico system helped simplify all processes. It proved to be an asset in the recruitment and ergonomics of workers in the class sorting phase because the boards are left on the met, which requires less effort.

One of the essential factors is the significant reliability of the automatic sorting, compared to the worker's non-automatic sorting if the machine is well programmed and aligned with the defined standards. However, there is still no evidence of time savings in this process, given that the machine is still in a testing and tuning phase.

One problem is automatic sorting software that does not migrate data to TrakSYS platform. That does not allow real-time visualization of global data, with that data being placed manually on the TrakSYS Platform, repetitively and with a more significant margin for error (greater human intervention).

I 4.0 can help the entire production process through vertical and horizontal integration (integrate all movements from raw material purchase, production, inventories, and shipment in real time), cloud computing (store data and queries), simulation (test various process improvement scenarios from raw material to final product shipment), sensors and actuators (integrate systems installed along the portico and mats with information transmission and help in optimizing the use of the machine and the reduction of production times), and IoT (integration of all hardware connected via wireless).

These tools provide real-time information, helping production management acquire only the necessary raw materials, reducing product waste and human actions. Another critical point is documentation simplification, which makes it possible to increase product monitoring, in terms of quality, without resorting to many workers.

I5.0 highlights sustainability through the 6Rs. In this process, it is possible to make the most of the raw material without waste, achieved through adaptability (exchange of jobs, removing employees from the task of cutting cork and relocating them to other functions or departments), safety and protection (reduce the number of workers in more insecure functions and improve technological resources), control and clarity (making data available in real-time, through existing software), customer satisfaction (making the process automated and meeting the customers' needs, through a common definition of the desired quality standards) and personalization (enabling the customer to sort a product, quantities, quality, and characteristics). Table 7 compares the two realities (previous and actual) in the Preparation Section and improvements.

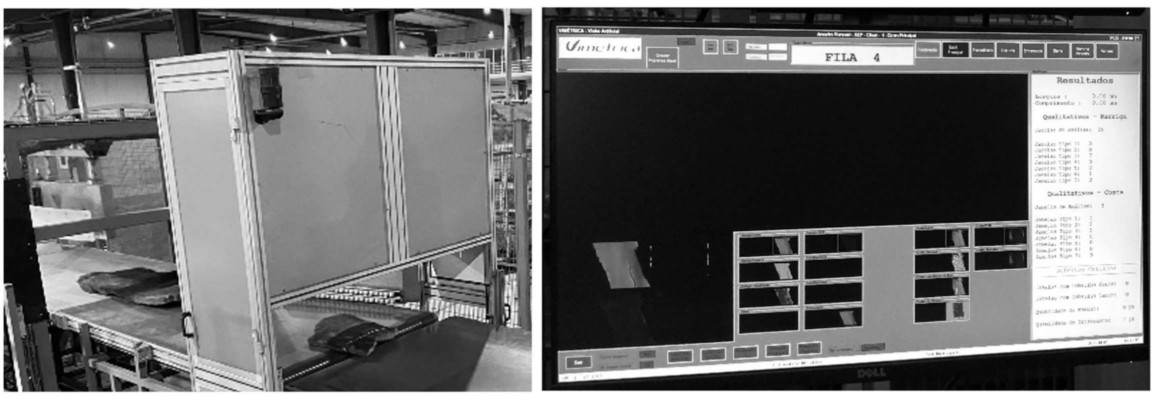
Table 7. Preparation section—Comparison of the previous and actual realities and improvements

Preparation Section—*Second sorting of cork*				
#	**Previous reality**	**Actual reality with LM & I 4.0/5.0**	**Obtained improvements**	**Future improvements**
1	Sorting of *delgado* by gauge (2 options) and class (6 options)	Sorting of *delgado* by gauge (2 options)	No sorting by classes, less complexity, minor specialization, placement of a mat where the sorting of gauge and cut was also made	Place a mat where the sorting of the *delgado* gauge was also made
2	Sorting of *cheio* by gauge (4 options) and class (6 options)	Sorting of *cheio* by class (6 options)	Less complexity, minor specialization	Place a portico for *cheio* sorting by class
3	Sorting manual calibration	Automated sorting	Greater reliability of sorting; greater customer satisfaction, and customization possibility per customer (standards tailored to your needs)	
4	Manually remove the cork from the pallet (greater effort)	Loose corkboards along the mat for sorting	Reduction of physical effort	
5	TrakSYS platform registration	Sort on the machine without connection to TrakSYS platform, manual records		Passing (migration) of information automatically to the TrakSYS platform (increasing the system reach)
6	Cutting the end of the board manually	Cutting the end of the corkboard manually		Placement of a met cutting automatism that reduces accidents with more safety

Process Improvement Proposals

Process improvement proposals were obtained by participant observation and comparison of previous and actual situations. Through informal conversations with workers and the observation carried out, it was possible to see that sorting classes still requires some observation time and experience in the area. The proposal is to place one more portico or a set of sensors along the met to determine the corkboards' classes. Figure 15 presents a prototype of a reading portico.

Figure 15. Reading portico prototype
Source: Industrial cork unit



Actually, *cheio* sorting process automation is taking place. It is essential to integrate the *delgado* sorting gauges, including a mat and the programming of the frame, for this purpose. This improvement would make it possible to reduce the number of workers from four to two at the beginning of the mat. It was found a more significant human effort in the process at the beginning of the mat. In this area, the worker must remove the corkboards from the pallet and reach the entire area, making him move to the surrounding areas. This phase requires special attention, so a robotic arm is proposed to remove the corkboards from the pallet and place them on the mat [Figure 16 (a)]. It is also important the inclusion of a lifting platform with a swivel top to put the pallet at the worker's height, so he did not have to bend to remove the corkboards, reaching them at the other end in a more comfortable work position (Figure 16 (b)).

Figure 16. Example of an Industrial robotic arm and a lift platform with swivel cover
Source: DF Robotics and Saxlift

These improvement proposals aim at a better and more efficient sorting process and workers' ergonomics and work safety so that the workers' skills can be used for tasks of greater intellectual complexity.

CONCLUSION

This case study concludes that it is possible to further reduce product waste and human actions, simplify existing documentation, and increase product quality monitoring without using a large number of employees.

To optimize and make the best use of the new resources available, the sorting mats and portico implementation reduce the people's physical effort and simplify the selection process. However, the software used by the automatic sorting machine is not integrated into the TrakSYS platform.

Improvement: The company could optimize and monetize existing resources with an extension of the TrakSYS platform with automatic data migration from the new portico, making it possible to obtain data in real-time and compile all the information in a single software, simplifying the entire analysis of the production process without human intervention and with access to information anywhere. As there is less complexity at the beginning of the human part of the process, it is possible to reduce the number of workers in this job

To increase efficiency and improve quality, the portico turns the process of sorting more automated and straightforward, as it is carried out according to the standards defined by the customer. This evolution, using I 4.0, already includes some principles of I 5.0, such as reduction of repetitive tasks by human actions, clarity, and control of the process, increase in customer satisfaction, reduction, and elimination of waste from the material raw material to the final product, and reduction of the complexity of the production process.

Improvement: The company could install a portico for the cork grade sorting and extend this automated sorting of gauge and grade to the cork that produces cork discs, which would increase the sorting reliability and increase customer satisfaction while also customizing patterns with the customers' needs.

To increase workers' safety, the process automation focuses on the cork sorting, but throughout the process, it becomes necessary to place the board on the mats and carry out a manual cut of the end of the corkboard.

Improvement: The company could install a robot to place the boards on the mats, a portico with a cutting system, and a lifting platform to increase worker safety and protection, thus reducing accidents and absenteeism.

As future research it is intention to carry out a study after the implementation of all the automation equipment, focused on time and resource indicators to analyze and restructure the Company's KPIs.

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