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DEPARTMENT OF MECHANICAL ENGINEERING

New Robotics paradigm with Collaborative Robots (Cobots)!

Project Report to fulfill the master's degree in Industrial Engineering and
Management

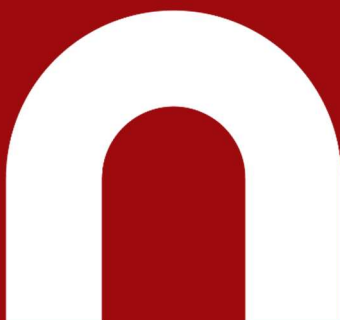
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ABSTRACT

Understanding the impact of human-robot coexistence on society and the global industrial landscape is crucial for assessing its benefits to both our quality of life and professional environments. This exploration involves identifying current trends and the trajectory of emerging technologies, with a specific focus on robots. Furthermore, it emphasizes the need for awareness in navigating the rapidly evolving landscape of technology, where choices between offers and opportunities shape experiences and contribute to sectoral and business prominence.

Objective: The objective of this project is to develop and analyze the applicability of collaborative robots in mechanical and hydraulic presses, with a focus on improving efficiency, safety, and quality of work in the industry, particularly within the context of Industry 5.0

Methodology: The methodology adopted involves conducting a SWOT analysis and utilizing virtual simulations to evaluate the introduction of collaborative robots in mechanical and hydraulic presses. The study focuses on critical points such as: increasing efficiency and reducing operational costs; improving product and service quality; enhancing flexibility in industrial production; improving worker safety and quality of life; and retaining talent by fostering a feeling of belonging. Challenges such as integrated and secure communication between means of production; a safe movement environment between machines, robots, and workers; programming to detect non-conformities; requalification and training of employees; resistance to organizational change; and diverse parts handling are also addressed.

Results and conclusions: Expected results include a detailed analysis of the direct and indirect benefits of implementing collaborative robots on three specific presses, focusing on machine/human resource management, operational efficiency, and effectiveness. The final implementation is anticipated to demonstrate significant improvements in terms of productivity, safety, and quality of work, with a projected ROI within 12 months. The SWOT analysis and practical implementation demonstrate that the integration of such technologies is viable and beneficial, positioning the organization to stand out in the global industrial landscape, contributing to the ongoing evolution of human-robot collaboration.

KEYWORDS: Cobots (Collaborative Robots); Industrial Automation; Operational Efficiency; Worker Safety; Press Machine Integration

RESUMO

Compreender o impacto da coexistência homem-robot na sociedade e no panorama industrial global é crucial para avaliar os seus benefícios tanto para a nossa qualidade de vida como para os ambientes profissionais. Esta exploração envolve a identificação das tendências atuais e a trajetória das tecnologias emergentes, com especial incidência nos robots. Além disso, salienta a necessidade de consciência para navegar no contexto tecnológico em rápida evolução, onde as escolhas entre ofertas e oportunidades moldam as experiências e contribuem para a proeminência setorial e empresarial.

Objetivo: O objetivo deste projeto é desenvolver e analisar a aplicabilidade de robots colaborativos em prensas mecânicas e hidráulicas, com foco na melhoria da eficiência, segurança e qualidade do trabalho na indústria, particularmente no contexto da Indústria 5.0

Metodologia: A metodologia adotada envolve a realização de uma análise SWOT e a utilização de simulações virtuais para avaliar a introdução de robots colaborativos em prensas mecânicas e hidráulicas. O estudo foca em pontos críticos como: aumento da eficiência e redução de custos operacionais; melhoria da qualidade de produtos e serviços; aumento da flexibilidade na produção industrial; melhoria da segurança e qualidade de vida dos trabalhadores; e retenção de talentos através da promoção do sentimento de pertença. São ainda abordados desafios como a comunicação integrada e segura entre os meios de produção; um ambiente de circulação seguro entre máquinas, robots e trabalhadores; a programação para deteção de não conformidades; a requalificação e formação dos trabalhadores; a resistência à mudança organizacional; e o manuseamento de peças diversas.

Resultados e conclusões: Os resultados esperados incluem uma análise detalhada dos benefícios diretos e indiretos da implementação de robôs colaborativos em três prensas específicas, com foco na gestão de recursos humanos/máquinas, eficiência operacional e eficácia. Prevê-se que a implementação final demonstre melhorias significativas em termos de produtividade, segurança e qualidade do trabalho, com um ROI projetado para 12 meses. A análise SWOT e a implementação prática demonstram que a integração destas tecnologias é viável e benéfica, posicionando a organização para se destacar no panorama industrial global, contribuindo para a evolução contínua da colaboração entre humanos e robots.

PALAVRAS-CHAVE: Cobots (Robots Colaborativos); Automação Industrial; Eficiência Operacional; Segurança do Trabalhador; Integração de Máquinas de Prensa

CONTENTS

ABSTRACT	2
RESUMO	3
CONTENTS	4
List of Figures	6
List of Tables.....	7
List of Abbreviations	8
CHAPTER 1 - INTRODUCTION.....	9
1.1. Framework	10
1.2. Factory general description.....	10
1.3. Report structure	11
CHAPTER 2 - METHODOLOGY	13
2.1. Description of the Study Context.....	13
2.2. Research Methodology	14
2.3. Implementation Procedures	15
2.4. Rating criteria	15
CHAPTER 3 – FRAMEWORK	19
Section I - COBOTS - Theoretical Framework	19
3.1. Macroeconomics objectives	19
3.2. Macro structural advantages.....	20
3.3. Proposal points for study and practical challenges	21
3.4. Features and structural micro-advantages – Benchmarking	23
3.5. Differentiation	27
3.6. Applications	28
Section II - PRESSES - Theoretical Framework.....	30
3.7. Presses	30
3.8. Cases in world	33
Section III - SAFETY - Theoretical Framework.....	34
3.9. ISO 10218, ISO 15066 and others international directives	34
Section IV – FACTORY DEVELOPMENT	37
3.10. Initial Analysis	37
Additional comments:	41
3.11. Implementation Proposals.....	47
3.12. Simulation and Testing	51

3.13. Pilot Implementation	57
CHAPTER IV - DISCUSSION	60
4.1. Analysis of Results	60
4.2. Benefits and Challenges	60
4.3. Comparison with Previous Studies.....	60
Lessons learned and best practices:.....	61
CHAPTER 5 - CONCLUSIONS AND FUTURE DEVELOPMENTS	63
Study Contributions	63
Industrial Contributions	64
REFERENCES	66

List of Figures

Figure 1 – Report structure. Created by Author (2024).....	12
Figure 2 – SWOT Analysis. Adapted from Author (2024).....	18
Figure 3 – SMART criteria “Increase operational efficiency” - Adapted from Author (2024).	19
Figure 4 - SMART criteria “Enhance worker safety” - Adapted from Author (2024).	19
Figure 5 - SMART criteria “Improve product quality” - Adapted from Author (2024).	20
Figure 6 - SMART criteria “Reduce operational costs” - Adapted from Author (2024).	20
Figure 7 - Benchmarking Research Process. Created by Author (2024).	27
Figure 8 - Business Strategies 2022 - Production & Expedition Department (Schedule of some proposed actions). Created by Author (2021).	45
Figure 9 - Business Strategies 2023 - Production & Expedition Department (Schedule of some proposed actions). Created by Author (2022).	45
Figure 10 - Business Strategies 2024 - Production & Expedition Department (Schedule of some proposed actions). Created by Author (2023).	46
Figure 11 – Presentation of internal Supply training. Created by Author (2024).	46

List of Tables

Table 1 - Geographic distribution of sales and service provision. Adapted from Author (2024).....	13
Table 2 - Evolution of main operational accounting items and net profit. Adapted from Author (2024).	14

List of Abbreviations

AI – Artificial Intelligence

AIoT – Artificial Intelligence of Things

CAD / CAM – Computer-Aided Design / Computer-Aided Manufacturing

CNC – Computer Numerical Control

IoT – Internet of Things

ISO – International Organization for Standardization

KPI – Key Performance Indicator

ML – Machine Learning

MODBUS – A communication protocol widely used in industrial automation systems.

PLC – Programmable Logic Controller

PME – Pequena e Média Empresa (Small and Medium-sized Enterprises)

ROI – Return on Investment

SMART – Specific, Measurable, Achievable, Relevant, Time-bound

SWOT – Strengths, Weaknesses, Opportunities, Threats

TCP / IP – Transmission Control Protocol / Internet Protocol

TUV – Technischer Überwachungsverein

XMLRPC – XML Remote Procedure Call

CHAPTER 1 - INTRODUCTION

Contemporary technological advancements offer exciting opportunities for individuals and businesses, impacting personal and professional aspects of individual and collective life across all levels of expertise. Recognizing technical innovation as a competitive advantage is crucial for organizations expanding into new domains. The technological journey often involves conversion, leveraging existing resources through minimal upgrades.

While certain business areas are in development, requiring dedicated research due to recent innovations, immediate advantages include enhanced communication, improved quality of life, increased productivity, and Industry 5.0, Wang et al., 2024, capabilities such as virtual connectivity. Despite challenges, embracing emerging technologies in business is a strategic imperative, providing a competitive edge through advanced possibilities for internal processes, products, and services.

An illustrative concept, Collaborative Robots (cobots), fosters interaction between robots and humans in the workplace. This collaboration combines the precision and power of robotics with human creativity and proactivity, manifesting true human-robot synergy, Wang et al., 2024, and exemplifying the potential of advanced technologies in enhancing overall value for customers. Cobots are robots designed to physically interact with humans in the same shared workspace. Unlike traditional industrial robots, which operate in isolated areas for safety reasons, cobots are equipped with advanced sensors and safety technologies that enable safe and efficient collaboration with human workers.

As part of the final dissertation for the master's degree in industrial management engineering at the Polytechnic University of Coimbra – Instituto Superior de Engenharia, I propose to develop and analyze at least one possible applicability of collaborative robots in mechanical and hydraulic presses within a factory/industrial context.

During my tenure in Production and Shipping Management at a metalworking manufacturing unit, five dominant needs emerged. This project proposes to analyze, in three specific presses, the direct and indirect benefits of managing machine/man resources in terms of efficiency and effectiveness. The project aims to defend and highlight the strategic acquisition of these robots for the production department, focusing on productivity, talent retention, digitalization, product quality, innovation,

and cutting-edge technology. Three keywords that can define this initiative are Integration, Understanding, and Opportunities.

1.1. Framework

The adoption of collaborative robots (cobots) aims to increase productivity, optimize processes and free workers from repetitive, heavy and dangerous tasks, improving safety and quality of work. Chiarini & Kumar, 2022.

Implementing cobots leads to greater efficiency, reduced operating costs and consistent product quality. It also promotes the digitalization of factories, retaining talent and encouraging innovation. The challenges include ensuring safe communication between machines and workers, integrating digital systems with existing processes and maintaining high quality standards. The cobots' flexibility allows them to adapt to new market challenges, strengthening the company's competitive position. This framework serves as a basis for exploring the benefits and challenges of integrating cobots in industry.

1.2. Factory general description

The company was created in 1965 through the merger of five competing saddle manufacturing companies in Águeda, Portugal. Realizing the competition between them and the lack of optimization of their offer on the market, they decided to join forces and form this company.

Years later, the company took on a new challenge and project, getting a new industrial building and expanding its team with new employees, resulting in a partnership between the two companies that was strengthened with the transfer of partner stamping and sheet metal cutting machines to this company.

Since 2012, this company has made strategic investments, including the acquisition of an oxygen laser cutting machine and stepping up with 4.0 technology since 2022 (fiber laser cutting, laser welding, 3000 bending machine, 3-axis CNC, semi-automatic crimping machine). This expansion has opened new production opportunities to attract customers and explore new markets: production of metal components for sectors such as health, automobiles and two-wheelers. Aiming to stand out through a strategy of differentiation and added value in the product value chain, the company seeks to develop high quality manufacturing solutions for industrial components, using advanced technologies adapted to emerging market

segments. With the vision of being recognized as a benchmark in manufacturing excellence, providing the best customer experience.

The company considers its Quality and Environmental Policy to be fundamental to the company's success. Efficient production processes, continuously improving its production and environmental practices, minimizing direct and indirect impacts. Promote awareness among the organizational tree, customers and suppliers, aiming for the lowest possible environmental impact. Values such as sustainability, integrity, customer satisfaction and social responsibility are essential to company.

Located in the municipality of Águeda, a region in central Portugal known for its strong industrial tradition, particularly in the metalworking sector, and recognized for the quality and innovation of its products. This plant stands out for its specialization in subcontracting the development of customer projects and parts, with the capacity to develop custom projects according to the customer's specifications. Use of CAD/CAM software for design, prototyping of parts and their development in industrial series. Implementation of rigorous quality control systems to ensure compliance with international standards, with ISO 9001 Certification. Following efficient stock and logistics management to guarantee just-in-time deliveries and strategic partnerships with transportation companies for export, especially to center of Europe with expansion into the eastern European market.

Innovation and Technological Development: The company continually invests in new technologies to improve its manufacturing processes. The introduction of collaborative robots in mechanical and hydraulic presses is an example of its commitment to innovation, aimed at increasing productivity, improving product quality and guaranteeing worker safety.

It was recently recognized as one of the innovation companies “INNOVATOR COTEC 2024”, following the COTEC-BPI PME Innovation Award, which annually distinguishes a list of PMEs that have stood out on the national (Portuguese) scene for their innovative attitude and activity. This achievement is the result of dedicated efforts to meet high customer requirements, supported by innovative practices and constant improvement, with a focus on minimizing environmental impact.

1.3. Report structure

Figure 1 outlines the structure of this report, providing a clear overview of the main sections and their corresponding content, ensuring a logical flow of the topics discussed throughout the document.

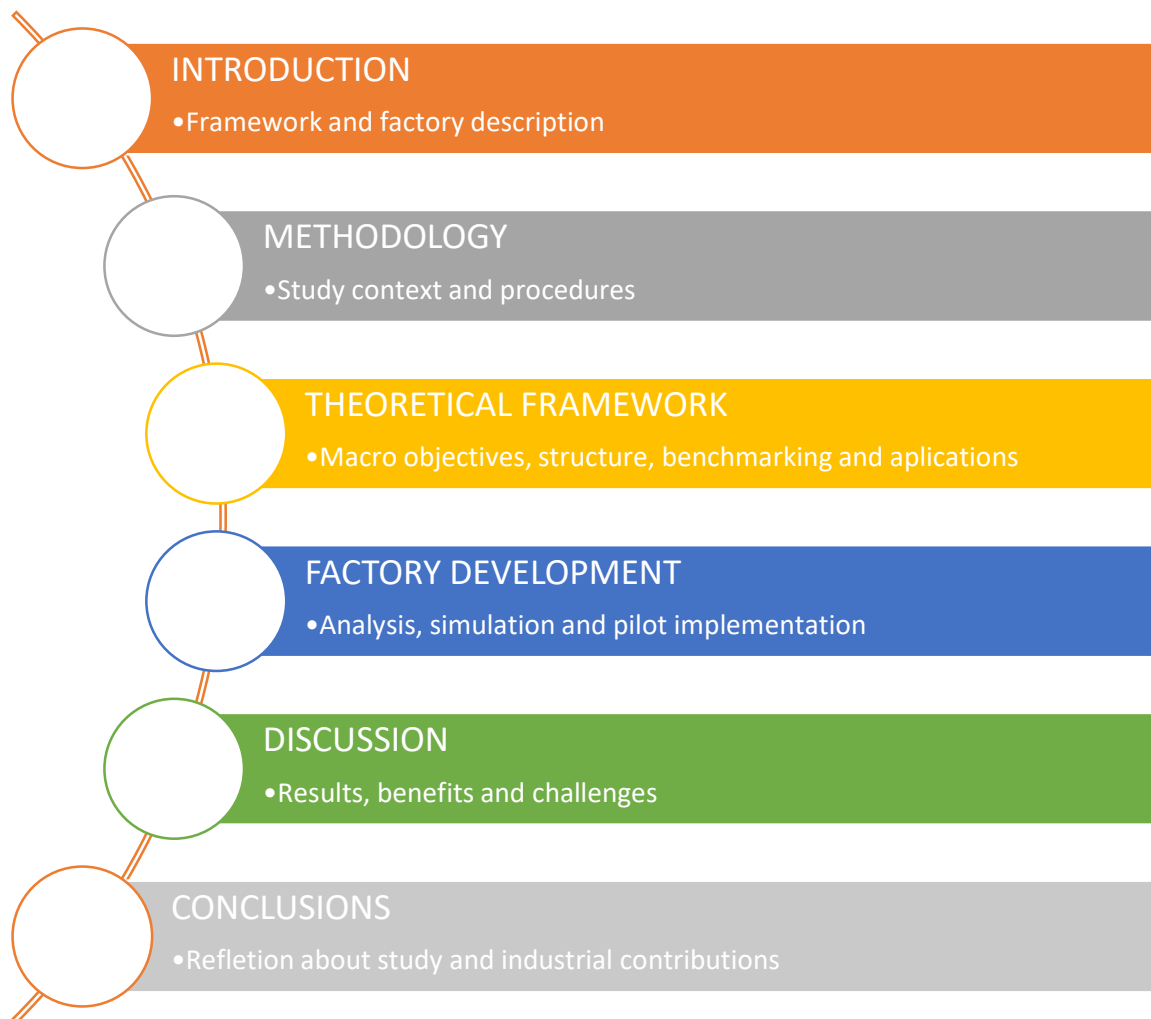


Figure 1 – Report structure. Created by Author (2024).

CHAPTER 2 - METHODOLOGY

2.1. Description of the Study Context

The study and project to introduce collaborative robots will be carried out in a modern industrial environment and with the ambition of being developed in a technically advanced manufacturing environment, at the company.

The context of the project, within its international industrial vision and strategy, is in line with the company's current action and practice of continually seeking innovation and improving manufacturing processes. Since 2012, the company has made strategic investments in advanced technologies, such as laser cutting machines and CNC machines, and since 2022, it has adopted Industry 4.0 technologies. The introduction of collaborative robots in mechanical and hydraulic presses is part of this modernization strategy, with the aim of increasing productivity, improving product quality and ensuring worker safety. Ali & Magdy, 2023. The company is also recognized for its quality and sustainability policy, aimed at minimizing environmental impacts and promoting awareness among employees, customers and suppliers.

In Tables 1 and 2, within the framework of economic and financial analysis, we can observe the evolution of operational costs and results, which are particularly relevant in highlighting the impact of innovation and improvements in manufacturing processes.

Table 1 - Geographic distribution of sales and service provision. Adapted from Author (2024).

Geographic distribution of sales and service provision.							
	MARKET	National market		International market			
	Total	Subtotal	%	Subtotal	%	Community	Extra-community
2021	3 540 657,62 €	3 154 019,41 €	89.08%	386 638,21 €	10.92%	10.92%	0.0%
2020	3 000 261,15 €	2 821 691,44 €	94.05%	178 569,71 €	5.95%	5.94%	0.01%
2019	2 928 476,85 €	2 651 452,32 €	90.54%	277 024,53 €	9.46%	9.15%	0.31%

Source: Management public reports 2019 – 2021

Table 2 - Evolution of main operational accounting items and net profit. Adapted from Author (2024).

Evolution of the last 3 years						
Headings	PERIODS					
	2019 (holder details)	2020 (holder details)	2021 (holder details)	2020	2021	
Sales and services provided	2 928 476,85 €	3 000 261,15 €	3 540 657,62 €	2%	18%	
Cost of goods sold and materials consumed	1 736 125,20 €	1 548 699,29 €	2 162 124,88 €	-11%	40%	
External supplies and services	364 444,49 €	352 763,84 €	496 164,81 €	-3%	41%	
Personnel expenses	702 428,35 €	689 183,31 €	702 782,90 €	-2%	2%	
Operating profit (before financing expenses and taxes)	- 21 279,67 €	103 403,01 €	40 605,09 €	586%	-61%	var % Operating results
Net profit for the period	- 48 854,12 €	68 093,88 €	21 502,54 €	239%	-68%	var % Net results

Source: Management public reports 2019 – 2021

2.2. Research Methodology

The focus of the study and development of this phase of robotization is on the cutting and forming of sheet metal, in the section of mechanical and hydraulic presses ranging from 35 to 315 tons. A 160-ton hydraulic press and two 65-ton mechanical presses stood out for eligibility. Points that stood out for election: machines exclusive to kanban production, repeated tasks; consolidated production processes; no non-conformities in the last 36 months; ergonomically prone to medium and long-term occupational injuries, with a stabilized workload with the possibility of increasing it to two shifts; workstations with consolidated kaizen, lean and 7's concepts, enabling one of the fundamental requirements for cobot-human cohabitation; production in the process of advanced and tested digitalization; and, from the point of view of the entire production team, completely familiar processes and mechanisms that no longer arouse technological curiosity. Payton & Gould, 2023.

2.3. Implementation Procedures

Following the Business Strategies and Frameworks - 2024 and the favorable and ambitious evolution of the KPIs of the planning, production and dispatch department over the last 5 years, in close correlation with the strategic vision of the management of company: digitalized production processes and a dashboard view of the factory with on-time results, incidents and productivity, Granata et al., 2024, the multi-pronged challenge of introducing and allocating collaborative robots is the CHALLENGE and the first step towards implementing Industry 5.0.

In parallel, there is the challenge of national and local industry: Reskilling and upskilling employees, aiding in the retention of young and promising talent, where we propose creating a progressive and technologically advanced work environment improves working conditions and offers progression opportunities.

2.4. Rating criteria

In order to measure the effectiveness of the implementation of cobots in the 160-ton press, we suggest combining quantitative and qualitative performance indicators over a period of six months (with the possibility of two-shift production), which will help in the analysis of the return on investment, but also in obtaining valuable insights for future optimizations and expansions of the use of technology and phased automation in other production segments. Navas-Reascos et al., 2023.

These include:

Effectiveness indicators - proposed for continuous monitoring such as productivity (1), product quality (2), safety (3), operating costs (4) and operator satisfaction (5).

$$\textit{Productivity per Working Hour} = \frac{\textit{Total Output}}{\textit{Total Working Hours}} \quad (1)$$

Definition: Measures the amount of output (production, services, completed tasks) generated for each hour of work.

$$\textit{Product Quality} = \left(\frac{\textit{Free Products} - \textit{Number of Defect}}{\textit{Total Number of Products Produced}} \right) * 100 \quad (2)$$

Definition: Measures the percentage of products that meet quality standards compared to the total number of products produced.

$$\text{Safety Incident Rate} = \left(\frac{\text{Number of Incidents}}{\text{Total Hours Worked}} \right) * 1,000,000 \quad (3)$$

Definition: Measures the number of safety incidents (e.g., accidents, injuries) per a certain number of hours worked. It helps track the safety performance of an organization.

$$\text{Operating Costs} = \frac{\text{Total Operational Expenses}}{\text{Total Output}} \quad (4)$$

Definition: Measures the total costs associated with the day-to-day operations of a business or process. This includes direct and indirect costs such as labor, materials, overheads, etc.

$$\text{Operator Satisfaction} = \left(\frac{\text{Total Satisfaction Score}}{\text{Total Possible Score}} \right) * 100 \quad (5)$$

Definition: Measures the level of satisfaction of operators or employees with their working conditions, processes, and environment. It is often determined through surveys or feedback tools.

Productive capacity - A study was carried out before and after the implementation of the cobots to quantify changes in cycle time (6), setup time (7) and utilization of press capacity (8).

$$\text{Cycle Time} = \frac{\text{Total Time Taken}}{\text{Number of Units Produced}} \quad (6)$$

Definition: Measures the total time taken to complete one cycle of a specific task or production process, from start to finish.

$$\text{Setup Time} = \frac{\text{Total Time for Setup Activities}}{\text{Number of Setups}} \quad (7)$$

Definition: Measures the total time required to prepare a machine, equipment, or process for a new production run. This includes all activities such as adjusting settings, changing tools, and ensuring the machine is ready to produce a different product.

$$\text{Utilization of Press Capacity} = \left(\frac{\text{Actual Production Time}}{\text{Total Available Time}} \right) * 100 \quad (8)$$

Definition: Measures the percentage of available capacity that is being used by the press in a given time period. It indicates how effectively the press is being utilized, helping to identify any idle time or inefficiencies.

Analyzing these indicators over time will help validate the effectiveness of the project and identify areas that need further adjustment or improvement. By cross-referencing the results of KPIs such as productivity, setup time, and utilization of press capacity, with the insights provided by the SWOT analysis, (below Figure 2), we can establish a clearer picture of the project's impact.

The SWOT analysis offers a strategic view, highlighting *Strengths* such as increased operational efficiency and improved worker safety using collaborative robots. However, it also points out *Weaknesses* like the potential resistance to organizational change or the need for extensive employee requalification. *Opportunities* arise from integrating advanced technologies, such as AI for non-conformity detection, which could further improve the effectiveness of the robots. Meanwhile, *Threats* like cybersecurity risks and handling a variety of parts add complexity to the process.

Each of the KPIs aligns with specific elements of the SWOT analysis. For instance, the *Utilization of Press Capacity* formula reflects how effectively the machines are used, directly linking to operational efficiency - a key strength identified in the SWOT analysis. *Setup Time* can reveal areas where operational flow may be hindered by slow processes, touching on both weaknesses and opportunities for optimization. Additionally, *Product Quality* indicators can be measured to see how well the cobots

are supporting the demand for higher standards, which ties back to the strategic opportunities for growth and market competitiveness.

By continuously monitoring and adjusting these KPIs in the context of the SWOT analysis (Figure 2), we can not only validate the success of the current implementation but also uncover specific areas where targeted improvements could be made, ensuring both the long-term sustainability of the project and its alignment with broader organizational goals.



Figure 2 – SWOT Analysis. Created by Author (2024).

CHAPTER 3 – FRAMEWORK

Section I - COBOTS - Theoretical Framework

3.1. Macroeconomics objectives

The core focus and purpose for organizations engaging in robotics lie in the specific outcomes they seek to achieve. Primarily, the emphasis is on enhancing and advancing automation tasks. Wang & Gao, 2022. Whether considering short or long-term objectives, these are typically articulated with clarity, guided by the SMART criteria, in the Figures 3 to 6, (Specific, Measurable, Achievable, Relevant, Time-bound), to the four main points of our SWOT analysis, presented in the last section.



Figure 3 – SMART criteria “Increase operational efficiency” - Adapted from Author (2024).



Figure 4 - SMART criteria “Enhance worker safety” - Adapted from Author (2024).



Figure 5 - SMART criteria “Improve product quality” - Adapted from Author (2024).



Figure 6 - SMART criteria “Reduce operational costs” - Adapted from Author (2024).

The overarching goals include the elevation of productivity Navas-Reascos et al., 2023, levels, the optimization of production processes, a heightened appreciation for workers' tasks, and the liberation from simple tasks — those that are repetitive, heavy, dirty, tedious, and potentially dangerous - tasks that hold limited added value for human beings. In essence, the objective is to strike a balance between the efficiency and effectiveness of the installed production capacity and competitiveness, thereby creating room and freeing up resources for its improvement and increase.

3.2. Macro structural advantages

In every phase of innovation, from suggestions for improvement to the implementation of new processes, the existing structure is the initial focal point for careful consideration, and we adhere to this fundamental principle.

The process of introducing robotics to a workstation or a production/dispatch or assembly line requires a detail and a meticulous study and examination to establish a new flow of movement. Ensuring the safety of human cohabitation is paramount, with the steadfast commitment to upholding order lines and meeting customer needs. Navas-Reascos et al., 2023.

The current array of offerings in collaborative robots affords us the ability to maintain the integrity of existing machinery and flow with minimal layout changes. Additionally, the flexibility for internal autonomous relocation in short to medium-term periods is a notable advantage. Müller et al., 2023 - Integrating sustainability into industries 4.0 and 5.0. Specific optimization and uniqueness are achieved through the adaptability inherent in this technology and the diverse formats in which it is introduced to the market. Importantly, the incorporation of collaborative robots reduces risks for human employees by executing non-ergonomic operations. These advantages serve as invaluable allies and positive reinforcements, all without necessitating an imperative back-office investment Navas-Reascos et al., 2023.

3.3. Proposal points for study and practical challenges

1. **Strategic Acquisition of Collaborative Robots: Boosting Productivity and Innovation in the Production Department.**

- **Increased Efficiency and Reduced Operating Costs:** Optimize precision and speed, enabling operations up to 24 hours/day, 7 days/week. Cobots can significantly increase production efficiency and speed by performing repetitive tasks with precision and without pauses. This captures new business opportunities through differentiation and improves energy efficiency.
 - **Challenge:** Integrated, fluid, and secure communication between means of production with conditioned human surveillance.

2. **Improvement in Worker Safety:**

- Reduction of absenteeism, physical effort, and injuries. Cobots minimize the need for workers to perform dangerous or repetitive tasks.
 - **Challenge:** Ensuring a safe movement environment between machines, robots, and workers.

3. Consistent Quality:

- Ensuring accuracy and reducing human error, leading to uniform product quality and increased customer satisfaction.
 - **Challenge:** Programming cobots to detect non-conformities.

4. Digitalization:

- Incorporating cobots is a crucial step towards factory digitalization, integrating intelligent production systems and collecting data for analysis and optimization.
 - **Challenge:** Effective integration of digital systems with existing production processes.

5. Product Quality:

- Cobots ensure higher product quality by reducing human errors and variations.
 - **Challenge:** Maintaining high standards consistently.

6. Retention of Talent and Workforce:

- Creating a progressive and technologically advanced work environment improves working conditions and offers progression opportunities, aiding in the retention of young and promising talent.
 - **Challenge:** Reskilling and upskilling employees and managing resistance to organizational change.

7. Innovation:

- By freeing human resources from monotonous tasks, cobots enable a focus on more creative and strategic activities, driving innovation within the company.
 - **Challenge:** Encouraging continuous innovation and adoption of new processes.

8. Production Flexibility:

- Cobots are programmable and can quickly adapt to new market challenges, such as changes in product lines or designs.
 - **Challenge:** Handling diverse parts efficiently.

9. Cutting Edge:

- Investing in cobots demonstrates a commitment to modernization and technological advancement, enhancing the company's reputation and competitive position.
 - **Challenge:** Keeping up with rapid technological advancements.

By addressing these points in a positive and empathetic manner, we empower the Unit's multidisciplinary teams to achieve continuous success, promoting a culture of excellence, responsibility, and commitment to the highest standards of quality and performance. Key points include showcasing the team's history, highlighting challenges faced, achievements reached, and future goals. Makris et al., 2022.

3.4. Features and structural micro-advantages – Benchmarking

The Benchmarking research process, (Figure 7), from a competitive and functional perspective, with the objective of identifying opportunities for improvement and adopting proven methods to increase the efficiency, quality and performance of the organization, in a comparative approach of products, services and even business practices in relation to leaders and competitors in the sector (or recognized best practices), it is a powerful tool that will enable organizations to learn from the successes and challenges of others. Internally allowing companies to critically analyze their own processes Wang et al., 2024, and metrics. This may involve the evaluation of operational practices, marketing strategies, production processes, quality of products and services, among others. Varela, Santos & Machado, 2023.

Through individual research encompassing diverse readings from various sources, such as attending the EMAF (International Fair of Machines, Equipment, and Services for Industry, scheduled to return to Exponor from May 31 to June 3, 2023), the Author (Paula Coelho) collected meticulous and diversified information. Additionally, she conducted a popularity ranking analysis and engaged in direct benchmarking discussions with suppliers within the business group to which she is affiliated (Figure 7).

In this research process, in which the Author chose eleven products, led her to identify and collect fifty key characteristics deemed of significant added value. These characteristics will form the foundation for an in-depth study exploring the feasibility

of implementing a new version of the robotic concept - specifically, the collaborative robot Wang et al., 2024.

Regarding this, it was made sense to categorize the features for the potential implementation of a collaborative robotization unit into four broad groups.

A) **Structural** (characteristics) - that contribute to competitive and strategic advantages over the base physical, incorporating considerations for the financial, economic situation, and workforce), Wang et al., 2024.

Compact footprint (primarily equivalent to the space required by an operator, with the added benefit of retaining a reserved and standardized area after careful study).

Cutting-edge Safety System (top-nach) with collision sensitivity, negating the necessity for safety barriers or bulky fencing for cohabitation.

Seamless integration with existing machinery, facilitating communication with other industrial equipment, robots, and peripherals (PLC, CNC, conveyors), and compatibility with a variety of software systems.

Diverse and versatile market offerings of collaborative robots tailored or adaptable to each business area.

User-friendly maintenance and repair processes, enabling the upkeep of the existing workforce without the need for additional technical hires.

B) **Quality** (characteristics contributing to competitive and strategic advantages in the products and/or services produced, along with ensuring the safety of the production environment and the sustainability of new means):

- a) Enables precise and accurate repeatability of operations.
- b) Incorporates a light alert system for effective communication with operators.
- c) Ensures accuracy in part positioning.
- d) Accommodates tasks ranging from light and simple to heavy and non-ergonomic.
- e) Offers the potential for a calibration board and wick sticker.
- f) Features six torque sensors in each joint to promptly respond to potential collisions.
- g) Guarantees maximum uptime and productivity.

- h) Utilizes camera and light technologies for recognition and localization, facilitating productive relocations for new projects Navas-Reascos et al., 2023.
- C) **Hardware** (characteristics of competitive and strategic advantage with implementation within the existing technical and operational staff):
- a) The robot showcases a state-of-the-art articulated robotic arm with lightweight components, setting the stage for unparalleled performance. The incorporation of a Double-joint or Dual-joint module elevates movement and flexibility, contributing significantly to the overall adaptability of the system.
 - b) The kinematic structure assumes a pivotal role in comprehending and managing the robot's movements, exerting direct influence over trajectories and orientations. This feature provides exceptional flexibility across various work scenarios. The inherent modularity within the robot enables seamless adaptability and customization, addressing specific needs and tasks efficiently.
 - c) Furthermore, the robot encompasses a multitude of additional technical and hardware characteristics, solidifying its performance and versatility. With optimized tool speed, a stabilizing apartment base, and a versatile shape, the robot establishes itself as a robust platform suitable for diverse applications.
 - d) In addition to these attributes, it integrates a flange-mounted camera to enhance visual perception, an efficient suction pump, and portable robotics mobility, facilitating usage in diverse environments. Its specialized properties, such as tolerance to extreme temperatures, underscore its resilience in challenging conditions. The modular design includes positioners with linear axes, offering one to three stations with bidirectional and multiturn axes, providing tilting and rotating movements. An anti-glare protective coating prevents unwanted reflections, while adjustable weight and reach ensure adaptability to specific requirements. Further setting it apart are its flexibility, compact size, and efficient operation on single-phase electrical networks, rendering it a comprehensive technical and hardware solution capable of effectively addressing a multitude of challenges.
 - e) Highly flexible 6 DOF collaborative robot (DOF - Degrees of Freedom): the highly flexible 6 DOF collaborative robot, with its ability to move in six different directions, primarily rotating around three Cartesian axes (x, y, z) and translating along these axes, offers a broad spectrum of three-dimensional movements. This adaptability makes it a key asset in dynamic and evolving work environments.

- f) The adaptive gripper emerges as a standout feature, boasting robustness and competitiveness within the realm of collaborative robots. This versatile tool encompasses various gripper types, including vacuum gripper, parallel gripper, flexible gripper, pen holder, cylinder, phone holder, pneumatic gripper, servo gripper, and two or three-finger gripper. The gripper's adaptability and diverse functionality empower the collaborative robot to handle an extensive range of tasks, further solidifying its significance in the ever-changing landscape of work environments.

D) **Software** (characteristics of competitive and strategic advantage with the implementation and compatibility of all existing means):

- a) Featuring an intuitive interface, users benefit from a design that prioritizes user-friendliness, ensuring effortless navigation and interaction. The incorporation of 3D visualization offers an advanced graphical representation, enriching the understanding of processes.
- b) A touch screen interface adds a tactile dimension to control, contributing to the overall intuitive nature of the software. Remarkably, programming experience is not a prerequisite, simplifying user engagement and making the software accessible to a broader audience.
- c) The installation process is streamlined, ensuring efficiency and minimizing downtime. Intelligent communication protocols, including EtherNet/IP, ProfiNet, TCP/IP, MODBUS, and XMLRPC, establish compatibility with diverse communication standards, guaranteeing seamless integration.
- d) Artificial intelligence capabilities further elevate the software, enabling enhanced decision-making and adaptability to varying scenarios. Compatibility with PC, Bluetooth controllers, and APP control ensures versatility in managing the software.
- e) Support for WIFI and RS485 communication protocols adds flexibility, catering to both wireless and wired communication needs. The overall intuitive design and ease of use make the software accessible to users with varying levels of technical expertise.
- f) In summary, this comprehensive suite of software features not only meets current technological standards but also establishes a foundation for future adaptability and innovation.

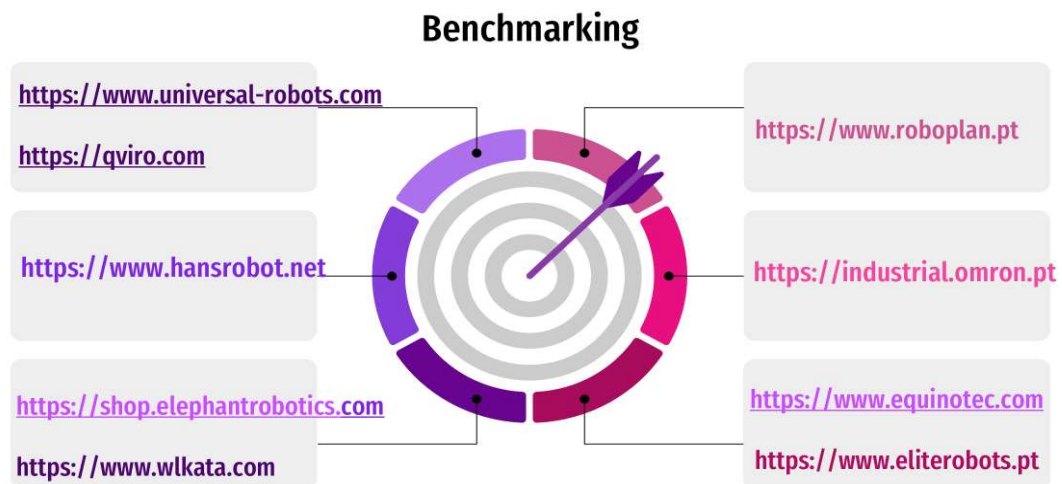


Figure 7 - Benchmarking Research Process. Created by Author (2024).

3.5. Differentiation

Once a physical work base is established, each supplier and, consequently, each production unit aims to distinguish itself by investing in collaborative robotics as a key strategic tool.

Featuring autonomous relocation capabilities, the system ensures flexibility and adaptability. The safety aspect is reinforced by a TÜV-approved and certified robot safety system, guaranteeing a secure operational environment.

The inclusion of a Smart Factory educational application with AI Vision and a Sorting Educational Tool enhances the system's educational value. From high-precision drawing to laser engraving, the professional-grade tool facilitates hands-on learning, enabling students and researchers to simulate real-world robotics and AIoT applications directly on a desktop. Barravecchia et al., 2023.

The robot's capability streams are further enriched by intelligent sensors in every joint, designed to detect potential contacts with humans or objects in its path. The high precision is complemented by excellent position repeatability and superior motion control, allowing the robot to execute tasks with the accuracy and consistency crucial for applications demanding precision and attention to detail. This comprehensive set of features positions collaborative robotics as a cornerstone in advancing technological capabilities within various industries.

Boasting a proven user interface with visual programming and fault management capabilities, the collaborative robot (cobot) establishes itself as an easily onboarded

and operated tool. Incorporating innovative features such as a multi-usage wrist with a colored ring annunciator and collision sensing capabilities, the cobot ensures safe operations alongside human operators and other machinery. Its adaptability shines through easy teaching procedures, offering greater diversity in smaller quantities, even within serial production lines. Wang et al., 2024.

The cobot minimizes the need for extensive programming, adhering to ISO 10218 and ISO 15066 standards. With a no-coding and no-hanging-food approach, it simplifies processes while ensuring compliance with safety regulations. Enhancing its functionality, the cobot integrates an intelligent vision system for pattern recognition, object positioning, and barcode identification. This not only aids in vision but also represents a paradigm shift in collaborative robotics. Wang et al., 2024.

The plug-and-play software enables quick start-up and trouble-free maintenance, while low-inertia servomotors contribute to its efficient performance. With force reorientation capabilities ensuring safety, the cobot delivers industrial robot-level performance with superior process quality compared to standard practices. In essence, this collaborative robot emerges as a groundbreaking solution, redefining operational efficiency and safety standards in various industrial applications.

3.6. Applications

Integrating automation seamlessly into production lines, collaborative robots (cobots) offer a versatile set of applications across various industries. Their adaptability and efficiency shine in the following practical scenarios:

- i. *Assembly* - Cobots demonstrate exceptional prowess in assembling components with remarkable precision and consistency. Furthermore, their proficiency extends to small parts assembly, enhancing both precision and speed within various manufacturing operations.
- ii. *Assisted Puncture Surgery* - In the healthcare industry, cobots play a role in assisted puncture surgery, enhancing precision and reducing the margin of error.
- iii. *CNC Machine Tending* - Cobots are employed in the automation of CNC machine tending tasks, ensuring efficient operation and minimizing downtime.
- iv. *Grinding* - Cobots can handle grinding tasks with precision, providing consistent results in metalworking applications.

- v. *Loading and Unloading in Automotive Manufacturing* - Cobots efficiently handle the loading and unloading of seat parts in vehicles, contributing to streamlined automotive manufacturing processes.
- vi. *Logistics and Packaging* - Cobots optimize logistics and packaging operations, guaranteeing the efficient handling of products for shipment. Their pivotal role in packaging encompasses tasks such as sorting, packaging, and palletizing, all executed with remarkable efficiency.
- vii. *Material Handling* - Cobots are widely used in material handling tasks, including loading, unloading, and transferring items with precision.
- viii. *Metal Die and Stamping Tending* - Cobots efficiently tend to metal die and stamping operations, ensuring consistent and reliable outcomes.
- ix. *Pelletizing* - In the food industry, cobots contribute to pelletizing tasks, providing efficiency and precision.
- x. *Picking* - Leveraging advanced hand-guiding capabilities, cobots adeptly retrieve parts from bins and seamlessly position them on conveyors or assembly lines. This not only significantly reduces cycle time but also elevates overall efficiency. The multi-usage wrist of cobots proves invaluable in bin-picking applications, ensuring accurate retrieval and placement of parts, thereby enhancing the efficiency of material handling processes.
- xi. *Screw Driving* - Cobots streamline screw driving operations, ensuring accurate and reliable fastening.
- xii. *Spraying* - The application of spraying, such as painting or coating, is streamlined with cobots for uniform and controlled coverage.
- xiii. *Testing* - Cobots are employed in testing procedures, ensuring consistent and reliable quality control.
- xiv. *Welding* - Cobots are adept at welding tasks, including laser welding workstations, ensuring accuracy and quality in the welding process.

The versatility and adaptability of collaborative robots make them indispensable across an array of industries and applications, contributing to enhanced efficiency, precision, and overall operational excellence. Bengoa et al., 2022.

Section II - PRESSES - Theoretical Framework

3.7. Presses

Hydraulic and mechanical presses are essential industrial equipment for stamping, forming and cutting metal materials. Rauch et al., 2022.

In general, a brief description of the usual and traditional operation of these types of presses, considering different tonnage capacities, focusing on the context of the use of cutting, stamping, forming, pouring and progressive tools:

A) Hydraulic Presses

General operation:

1. **Hydraulic drive:** Hydraulic presses use a hydraulic system to generate the necessary force. This system consists of a hydraulic pump that pressurizes the hydraulic fluid, which is then used to drive a hydraulic piston or cylinder that applies the force to the stamping or cutting operation.
2. **Pressure and speed control:** The operating speed and pressure can be precisely controlled by means of hydraulic valves, allowing adjustments to be made according to the specific needs of the operation.
3. **Tonnage Capacity:** Hydraulic presses are available in a wide range of tonnage capacities, ranging from smaller models (such as 65 tons) to large presses of 315 tons or more, depending on the application and the size of the parts to be processed.

Tooling applications:

- **Stamping and Forming:** Stamping tools are used to shape sheet metal to the desired design.
- **Cutting:** Cutting tools are used to cut specific shapes in sheet metal.
- **Pouring:** Some hydraulic presses can also be used for pouring operations.

Additional features:

- **Flexibility:** Hydraulic presses are known for their flexibility in terms of adjusting pressure and speed during the operating process.
- **Quiet operation:** Comparatively, hydraulic presses tend to be quieter during operation compared to mechanical presses.

B) Mechanical presses

General operation:

1. **Mechanical Drive:** Mechanical presses use a mechanical drive system, where the force is generated by an electric motor that drives a flywheel or gears to apply the force to the stamping or cutting operation.
2. **Power transmission:** Power transmission occurs directly from the motor to the drive mechanism, providing high speed and precision.
3. **Tonnage Capacity:** Similar to hydraulic presses, mechanical presses are available in a wide range of tonnage capacities, from smaller models to large machines of 315 tons or more.

Tooling Applications:

- **Stamping and Forming:** Stamping tools are used to shape sheet metal by means of controlled pressure.
- **Cutting:** Cutting tools are applied to cut metal materials into desired shapes.
- **Progressive tools:** Some mechanical presses can be equipped with progressive tooling systems, allowing multiple stages of stamping and cutting operations in a single pass.

Additional features:

- **Operating speed:** Mechanical presses are known for their high operating speed, which makes them ideal for operations that require fast and efficient production.
- **Precision:** Due to their direct drive system, mechanical presses offer high precision in the control of force and speed during the process.

Final considerations:

Both types of press have their advantages and are chosen based on the specific needs of each industrial application. The choice between hydraulic and mechanical presses depends not only on the tonnage capacity required, but also on the characteristics of speed, precision, type of operation and operating cost.

C) Technical and Physical Characteristics of a 160 Ton Hydraulic Press

1. Capacity and Strength

- Nominal capacity: 160 metric tons

- Working Pressure: Approximately 3200 psi (220 bar)

- Maximum Force: 1600 kN

2. Structure and Construction

- Frame: Welded steel construction for high rigidity and durability

- Frame dimensions: Approximately 2500 mm (height) x 2000 mm (width) x 1500 mm (depth)

- Weight: Approximately 15,000 kg (depending on model and manufacturer)

3. Worktable

- Table area: Approximately 1000 mm x 800 mm

- Table height: Approximately 900 mm from the floor

- Piston stroke: Between 300 mm and 500 mm

- Maximum opening (between table and piston): Approximately 800 mm

4. Hydraulic System

- Hydraulic pump: High pressure pump with variable capacity

- Oil reservoir: Capacity of around 300 liters

- Speed control: Adjustable for different stamping and forming operations

5. Control System

- Control Panel: User-friendly interface with digital display and control buttons

- Automation: Possibility of integration with PLC (Programmable Logic Controller) systems

- Safety: Equipped with safety devices such as light barriers, emergency stop buttons and mechanical guards

6. Accessories and tools

- Matrix and Punches: Customizable according to the needs of the stamping project

- Quick Tool Change: Systems to facilitate and speed up tool changes

- Coolant System: To control the temperature of the hydraulic oil

D) Productive Scope

1. Processing capacities

- Processable Material: Steel, aluminum, copper and other metal alloys

- Sheet thickness: Variable, typically between 0.5 mm and 10 mm

2. Work cycles

- Stamping speed: Approximately 15 to 30 cycles per minute (depending on the material and complexity of the part)

- Production capacity: Can vary from 900 to 1800 pieces per hour, considering simple stamping operations

3. Common applications

- Sheet Metal Stamping: Production of metal components through cutting, bending and forming processes

- Sheet Metal Forming: Creating complex and detailed shapes for various industries, such as automotive, aerospace, and household appliances

- Production of Medical Components: Precise components for medical equipment and devices

4. Operational Advantages

- Precision and Repeatability: High precision in each cycle, essential for parts requiring tight tolerances

- Versatility: Ability to carry out multiple types of stamping and forming operations

- Safety: Integrated systems to ensure operator safety and equipment protection

A 160-ton hydraulic press for stamping and forming sheet metal is a robust and versatile piece of equipment, ideal for a wide range of industrial applications. Its technical and physical characteristics allow for a high level of precision and efficiency, making it an excellent choice for production processes that require strength, consistency and flexibility.

3.8. Cases in world

In a light-hearted tour of the world's news, two case studies were identified that could be particularly useful in bringing this study together with others on an international scale. Stojanovic et al., 2023. Both cases highlight the ability of cobots to increase productivity, reduce operating costs and deal with complex tasks, making them relevant motivating examples in the research being studied, analyzed and presented in this work.

FT-Produktion (Sweden): This company successfully increased its production capacity without adding new personnel by using a combination of collaborative robots (from On Robot and Universal Robots) and robot grippers. This automation solution allowed the company to achieve a return on investment (ROI) in just nine months. The simplicity in programming and the low cost of implementation were key factors in their success. This example could demonstrate how cobots improve efficiency and reduce operational costs.

Nike's Cobot Integration: Nike used cobots with innovative electro-adhesion-based grippers to assemble delicate sneaker components 20 times faster than humans. The technology allowed the cobots to handle fragile materials without damaging them, showcasing the precision and flexibility cobots can bring to manufacturing processes.

Section III - SAFETY - Theoretical Framework

3.9. ISO 10218, ISO 15066 and others international directives

ISO 10218 is an international standard that defines safety requirements for industrial robots. It directly addresses the safe interaction between humans and robots in the workplace. Here is a summary of the main points advocated by ISO 10218:

1. **General Requirements:** Establishes general safety principles for industrial robots, covering everything from design to manufacturing, integration, operation and maintenance.
2. **Risk Areas:** Identifies and classifies potential risk areas where human interaction with the robot may occur, such as work zones and robot movement zones.
3. **Safety Measures:** Defines specific measures to reduce risks, such as safety devices, emergency stop systems, physical protection and safe controls.
4. **Ergonomic Design:** Recommendations for the ergonomic design of robots and workstations to minimize the risk of injury to operators.

5. **Operating Instructions:** Provides guidance on the documentation required for safe robot operation, including operating manuals, operator training and maintenance procedures.
6. **Safety Validation:** Establishes methods for verifying compliance with safety requirements, including tests and risk assessments.

In summary, ISO 10218 aims to promote the safety of workers and the integrity of industrial processes where robots are used, ensuring that the interaction between humans and robots is safe and efficient.

ISO 15066 is an international standard that complements ISO 10218, focusing specifically on safe collaboration between industrial robots and humans. Here is a summary of the main points advocated by ISO 15066:

1. **Force and Pressure Limits:** Defines safe limits for the forces and pressures that a robot can exert during interaction with a human being. This includes limits to prevent injuries from physical contact.
2. **Speed Monitoring and Reduction:** Establishes guidelines for continuous monitoring of the robot's speed and position during collaborative operation, with the ability to automatically reduce the robot's speed in case of proximity to humans.
3. **Risk Assessment Guides:** Provides methods and guidelines for carrying out a detailed risk assessment of collaborative robot applications, considering variables such as speed, weight, power and type of interaction.
4. **Sensory Systems and Safety Devices:** Recommends the implementation of advanced sensory systems and safety devices, such as proximity sensors, vision cameras, light barriers and emergency stops, to ensure the detection and prevention of collisions or incidents.
5. **Safe Motion Control:** Defines requirements for motion control systems that allow for the rapid and safe interruption of robot operations in the event of an emergency or unplanned interaction with humans.
6. **Validation and Verification:** Establishes guidelines for validating and verifying the safety performance of collaborative robot systems, including practical tests, simulations and design reviews.
7. In summary, ISO 15066 was developed to help manufacturers, integrators and users of collaborative robots to design, implement and operate these systems safely, guaranteeing the protection of workers and optimizing the efficiency of industrial operations.

In addition to the ISO standards mentioned above (ISO 10218 and ISO 15066), there are specific guidelines and standards in Europe and at international level that address human-robot interaction in a safe way. Here are some of them:

European Guidelines:

1. Directive 2006/42/EC (Machinery Directive):

This European Union directive establishes essential health and safety requirements for placing machinery on the European market, including industrial robots. It addresses safety in the design, manufacture and integration of machinery, including human-robot interaction.

International Standards:

1. ANSI/RIA R15.06-2012 (American National Standard):

This American standard addresses safety for industrial robots and integrated systems, including requirements for human-robot interaction and protective measures.

2. ISO 13482:2014 (Robots and robotic devices - Safety requirements for personal care robots):

This international standard focuses on the safety of personal care robots but includes guidelines relevant to safe interaction between humans and robots in general.

Other Recommendations and Guides:

1. European Robotics Forum (ERF) Best Practice Guide on Risk Assessment and Safety in Robotics: Guides drawn up by European robotics experts to help with risk assessment and safety in the implementation of robotic systems, including interaction with humans.

2. National Institute for Occupational Safety and Health (NIOSH) Guidelines for Robotics Safety: United States guidelines that offer recommendations on safety in the operation of robots, focusing on worker protection and accident prevention.

These guidelines and standards are fundamental for guiding manufacturers, integrators, users and legislators in the safe implementation of robotic systems, guaranteeing worker protection and promoting the efficiency of industrial operations. Wang et al., 2024.

Section IV – FACTORY DEVELOPMENT

3.10. Initial Analysis

The tasks identified for automation with cobots include handling parts in the jig, pressing the buttons on the hydraulic press and moving the parts to the output chute. These activities were chosen because they are repetitive, monotonous and have little added value for employees, as well as presenting potential health risks due to repetitive effort and proximity to industrial machinery. Automating these activities aims to improve operational efficiency, free up human resources for more strategic tasks and increase safety in the workplace. Hansen et al., 2024.

In terms of all the tasks mentioned (handling parts in the jig, pressing the buttons on the hydraulic press and moving the parts to the output chute), here are the technical requirements and the feasibility of them being carried out by a cobot:

1. handling parts in the jig:

- Ability to identify and grip different types of parts accurately.
- Sensitivity to touch to ensure that parts are handled without damage.
- Precision and repeatability to correctly position parts in the jig.
- Integration with vision systems for part recognition and orientation.

As cobots are designed with advanced sensors and precise programming capabilities, enabling delicate and safe handling of parts, touch sensitivity and vision capabilities are common features in modern cobots, which makes this task suitable for automation with cobots.

2. Pressing the buttons on the hydraulic press:

- Sufficient force to press the push buttons with the correct amount of pressure.
- Precise button location to avoid operating errors.
- Integrated safety to prevent accidents during operation.
- Programming for precise synchronization with the press cycle.

Considerations: Cobots can be programmed to press buttons with precision and controlled force. However, it is crucial to ensure that the cobot is safely integrated

with the hydraulic press, following all safety regulations. Precise synchronization with the machine cycle is also essential to avoid damage to the press or the cobot itself.

This stage can now be replaced by the detection and interaction of signals between machines. In other words, unlocking by transferring the activation from two-handed mode to automatic mode by direct indication from the robot's system, with the guarantee that the part is positioned and ready for stamping.

3. Moving parts to the exit chute:

- Ability to pick up and transport parts efficiently.
- Precise placement of parts on the output chute.
- Speed and efficiency to optimize production flow.
- Sensing to ensure that parts are moved correctly.

Considerations for Cobots: they are suitable for repetitive and precise handling tasks. With their ability to be programmed for specific trajectories and integrated with vision systems, they can effectively transport parts to the exit chute. Accuracy in the placement of parts is guaranteed by the cobot's precise control.

In short, all the tasks mentioned are possible to automate with cobots, if the specific technical requirements for each one are taken into account. Modern cobots are designed to handle a wide range of industrial tasks, offering flexibility, safety and efficiency in the working environment

To define the study methodology for the project to implement collaborative robots (cobots) on the production line in the case study, a comprehensive survey of data and information was required. This included direct observations in the factory, interviews with various stakeholders, analysis of trends and emerging technologies at specialized fairs and research into real cases on social networks. Below, we detail each of these methodological steps, which were essential to ensuring the robustness and viability of the project.

Data collection

1. Factory observation

- Objective:
 - To identify the workstations and production processes that could benefit from the introduction of cobots.
- Method:
 - Direct and systematic observation of all workstations on the production line, favoring kanban piece production, recording activities, cycle times, interactions between operators and machines, and points of potential improvement.
 - Analyzing workflows and identifying repetitive and physically demanding tasks that are ideal for automation with cobots.

2. Interviews

- Suppliers:
 - Interviews with suppliers of collaborative robots to understand the technical capabilities, specifications and costs of the cobots available on the market.
 - Discussion of implementation best practices and success stories in similar industries.
- Colleagues and operators:
 - Conversations with line operators, supervisors and colleagues to gather insights into daily challenges, possible resistance and suggestions for improvement.
 - Assessment of employees' perceptions and expectations of automation and its impact on the working environment.
- Administrators:
 - Meetings with administrators and production managers to align the project with the company's business strategy, including productivity, quality and market expansion targets.
 - Discuss the available budget, expected return on investment (ROI) and implementation schedule.

3. Participation in technology fairs

- Objective:
 - Keep up to date with the latest trends in industrial automation and identify innovative technological solutions.
- Method:
 - Attending technology fairs and exhibitions, (such as Hannover Messe), to explore new cobot solutions and other automation technologies.
 - Gathering information on new functionalities, security improvements and integration with existing production systems.
 - Networking with industry professionals and collecting feedback on successful cobot implementations.

4. Social Media Research

- Objective:
 - To understand the practical use, limitations and perspectives of cobots through real cases shared on social networks and specialized forums.
- Method:
 - Monitoring discussions on professional social networks such as LinkedIn and forums specializing in industrial automation and robotics.
 - Analyzing posts, articles and comments to identify other companies' experiences of implementing cobots, highlighting successes, difficulties faced and solutions found.
 - Gathering data on feedback from users and experts who have already implemented cobots, providing a practical and detailed overview of the advantages and limitations of this technology.

Conclusion:

The methodology adopted for this study is structured and detailed, aiming not only to justify the investment in cobots, but also to demonstrate the tangible and intangible benefits that this technology can bring to the plant. The implementation of cobots promises to increase operational efficiency, improve product quality and create a safer and more innovative working environment, positioning the company for sustainable and competitive growth in the European market.

Through comprehensive data collection and detailed analysis, we are confident that the introduction of collaborative robots in production will not only bring significant

improvements in production KPIs, but will also strengthen our strategic position in the global market.

The methodology of this study is based on a systematic and integrated approach, aimed not only at improving production KPIs, but also at promoting innovation and strengthening the company's competitive position in the European market. The implementation of cobots promises to bring operational efficiency, superior quality and a safer, more stimulating working environment, enabling the company to achieve its strategic objectives of growth and expansion.

Additional comments:

1. The job chosen is repetitive and monotonous.
2. Occupational safety: Repetitive workstations can lead to repetitive strain injuries and other occupational health problems.
3. Consistency and Quality: Collaborative robots can perform tasks with greater precision and consistency than humans, guaranteeing more uniform product quality.
4. Increased Production Capacity: Automating repetitive tasks is intended to increase production capacity by rechanneling the strength of human capital and avoiding the need to hire more resources for short periods of time, instead focusing on medium-term projects where contracting will be more specific and provide added value.
5. Production flexibility: Collaborative robots can be reprogrammed quickly to handle different tasks or products, offering greater production flexibility.
6. Cost Reduction: Although the initial investment in a collaborative robot can be significant, in the long term it will result in cost savings due to labor optimization, less waste and greater efficiency.
7. Valuing Employees: By removing employees from repetitive, low value-added tasks, the company demonstrates a commitment to the well-being and professional development of its staff and Human Capital, which is intended to lead to greater employee satisfaction and talent retention.
8. Market Competitiveness: Automation and the implementation of advanced technologies, such as collaborative robots, is intended to help the company remain competitive in the market, meeting customer/market demands for high quality products/services and commitment to deliveries (fast - within the production cycle, allowing self-financing).

9. It can be highlighted that the introduction of a collaborative robot in this workplace not only improves conditions for employees, but also brings tangible benefits to the company in terms of efficiency, quality, flexibility and competitiveness; ‘Behavior breeds behavior!’

Since we want to promote talent and know how in the service of more mentally demanding jobs, we need to use arguments to keep them on side with this project of innovation for inclusion, without seeing the robot as a substitute for people:

Communicate clearly and transparently the benefits of introducing robots into the workplace and emphasize how it can improve conditions and opportunities for team members.

1. Professional Development Opportunities:

- Explain how the introduction of the collaborative robot allows the team to get involved in more complex and challenging projects, offering opportunities to develop new skills and technical competences (identify some in macro approach).

2. Focus on Tasks with Greater Added Value:

- Highlight how the automation of repetitive and low value-added tasks frees up time and resources for staff to focus on more strategic and intellectually stimulating activities, promoting a more rewarding and enriching working environment.

3. Collaboration with the Collaborative Robot:

- Emphasize that the collaborative robot is designed to work together with the team, to complement their skills and increase their efficiency. Emphasize the importance of human-robot collaboration and how this can boost innovation and the success of the team (multidisciplinary and departments).

4. Valuing the Team's Know-how and Expertise:

- Recognize and value the know-how and experience accumulated by the team over the last 5 years, where the organization has opened up to new markets. Showing how the knowledge and expertise of the team members is essential for guiding and optimizing the operation of the collaborative robot, ensuring its successful integration into the production process. Highlight the latest

Industry 4.0 investments on the shop floor, highlighting the macro and by analogy this new workforce.

5. Company growth and expansion:

- Share the vision of how the introduction of the collaborative robot can boost the company's growth and expansion, opening new business opportunities and strengthening its competitive position in the market. Identify 'tanks and new 'radiological' project. Emphasize how the team's success is fundamental to achieving these objectives in the medium and long term.

Communicate these arguments clearly and empathetically, contextualizing and helping to understand and accept the introduction of the collaborative robot as an opportunity to grow, develop and contribute to the company's success, without feeling that we are being replaced by machines.

MANUFACTURING ORDERS digitalization and inventory by QR code

The organization is managing to win value-added projects in the European market, especially in the hospital sector. It is important to highlight the positive aspects of the team and their new attitude and mindset. Emphasize the greater need for rigor, discipline, quality, cleanliness and compliance with product flows and concentration required during working hours. For two reasons: cohabitation of robots and "conquest" of the market.

1. The importance of quality and rigor:

- Explain how winning high-value projects in the hospital area requires high standards of quality, rigor and discipline in all aspects of work. Emphasize the importance of strictly following established procedures and workflows to guarantee excellence at every stage of the process.

2. The impact of cleaning and organization:

- Address the importance of cleanliness and organization in the workplace, especially in a sensitive area such as a hospital. Explain how cleanliness and organization contribute to safety, efficiency and the quality of end products, as well as conveying a professional image to customers.

3. The need to meet deadlines:

- Emphasize the importance of strictly adhering to project deadlines, considering the company's reputation and customer satisfaction. Show how discipline and concentration during working hours are essential to ensure that

deadlines are met consistently and reliably. The robot being directed towards the 'boring' and 'dangerous' frees up the employee for the important stuff.

4. Valuing the Will to Learn and Improve:

- Valuing the will to learn and the team spirit of one's own team, recognizing efforts to overcome obstacles and achieve challenging goals. Encouraging the continuous search for knowledge, improvement and excellence, emphasizing the fundamental role that each team member plays in this process.

At same time and in perfect harmony, progress was made with the final phase of digitizing manufacturing orders, digital control plans, on a checklist basis and the general inventory of products via QR Code. Being part of everyday life and obtaining more immediate and concrete visible results, reflecting how new technologies can help us in our daily lives, individually and collectively. It is considered to have been the turning point in the widespread mindset on the path to innovation and cohabitation with technology.

The sum of several stages and steps in the three-year period from 2022 to 2024, also the result of the annual proposal for Business Strategies – Production & Shipping Department, in Figures 8 to 11.

Proposed Actions :

- ✓ Implementation of 5S Methodology;
- ✓ Extension of quality control plans for all production;
- ✓ Submit production processes older than three years for reanalysis of structure and work instructions;
- ✓ Train operators to perform tasks effectively, efficiently and autonomously = “Right person in the right place” – Written Procedures;
- ✓ Process optimization: station x work environment analysis, MP displacement circuit analysis, parts and operator (Layout);
- ✓ Involvement / Responsibility of the parties – On the Job Training.

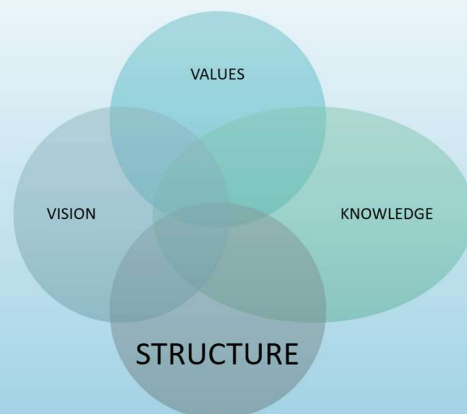
KPI - Target 2022

6

FIGURE 8 - Business Strategies 2022 - Production & Expedition Department (Schedule of some proposed actions). Created by Author (2021).

- Sharing of Industrial VISION and Added Value;
- Cultivate VALUES of belonging, positive attitude and open mind;
- Encourage and promote KNOWLEDGE as THE TOOL!

Organizational STRUCTURE



Direction & Monitoring – KPI 2023

FIGURE 9 - Business Strategies 2023 - Production & Expedition Department (Schedule of some proposed actions). Created by Author (2022).

Business Strategies 2024 by internal formation

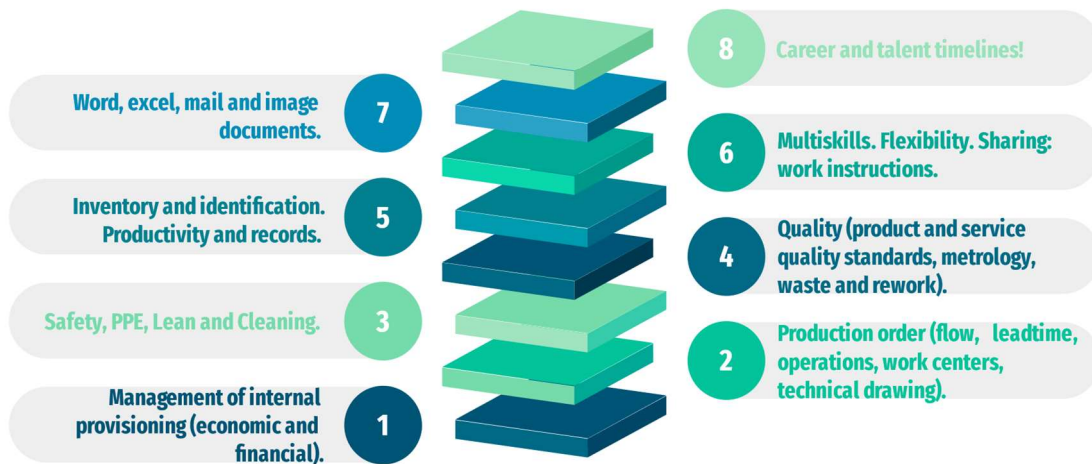


FIGURE 10 - Business Strategies 2024 - Production & Expedition Department (Schedule of some proposed actions). Created by Author (2023).

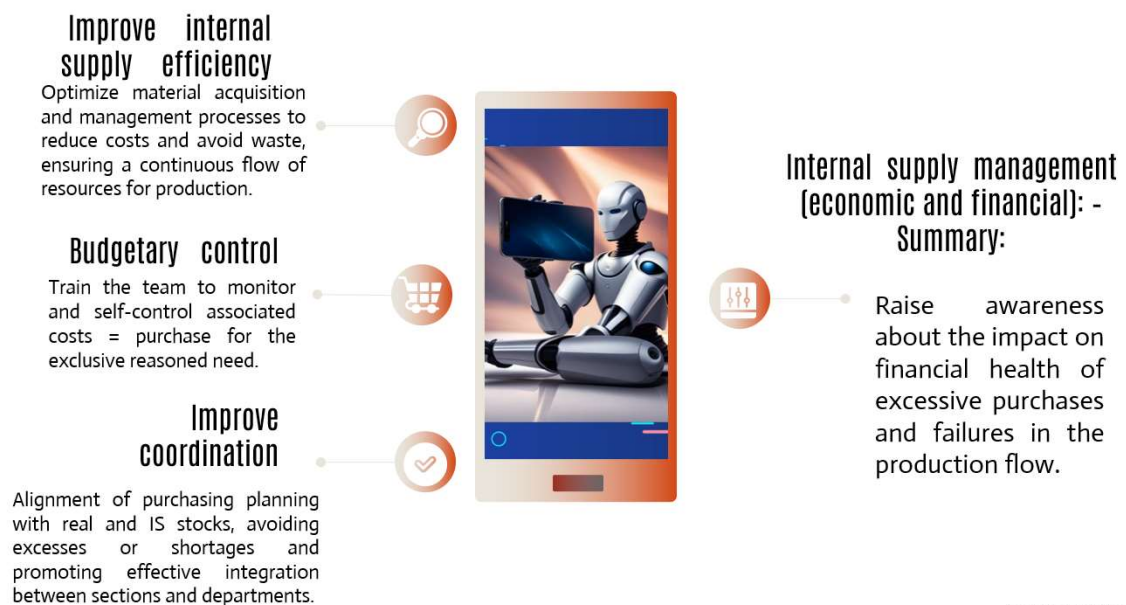


FIGURE 11 – Presentation of internal Supply training. Created by Author (2024).

3.11. Implementation Proposals

MACHINE:

The robot will interact with is a hydraulic press with a two-handed system. The machine is guaranteed to be 30 years old. Analyzing the workstation to position the robot before moving on to the next stage:

1. Safety assessment:
 - Evaluate the safety aspects of the workplace, considering the interaction between the collaborative robot and the two-hand hydraulic press. Ensure that the robot will be able to operate safely alongside the machine, guaranteeing the integrity of the employees.
2. Ergonomics study:
 - Analyze the ergonomics of the workstation, considering the movements and positions of the employees during the loading and unloading of the machine. Ensure that the collaborative robot will be able to carry out these tasks efficiently and ergonomically.
3. Layout and Available Space:
 - Check the current layout of the workspace and assess the space available for installing the collaborative robot. Consider the ideal location for positioning the robot in relation to the hydraulic press and other machines or equipment in the area.
4. Analyze the workflow:
 - Analyze the current workflow at the workstation, identifying the entry and exit points for the parts, as well as the machine's cycle times. To determine the ideal time for the collaborative robot to intervene and optimize process efficiency.
5. Compatibility with the Existing Machine:
 - Check the compatibility of the collaborative robot with the hydraulic press and its two-handed system. Make sure that the robot will be able to interact effectively and safely with the existing machine, without compromising its operation or functionality.

6. Maintenance and Accessibility Considerations:
 - Consider the maintenance and accessibility need of the collaborative robot. Ensure that the positioning of the robot will allow easy access for maintenance and repairs, guaranteeing the continuous availability of the system over time.
 - Carry out a comprehensive workplace analysis, with a clear understanding of the specific requirements and considerations for the robot's interaction work environment. Gotham et al., 2023.

OPERATION:

The operation consists of placing two parts, left and right, on a template, then pressing the buttons and stamping both simultaneously. Then remove the two pieces and let them slide centimeters in front of each other onto the left and right rails. And so on until a certain count is reached.

We can then identify the following key points to consider when positioning the collaborative robot:

1. Positioning the parts in the jig:
 - The robot must be positioned so that it has easy access to the two pieces that need to be placed on the template. This may require a strategic position that allows the robot to manipulate the parts with precision.
2. Interaction with the Press Buttons:
 - The robot must be able to press the hydraulic press buttons safely and accurately. This may require the installation of sensing devices or vision systems to ensure the correct alignment of the parts before stamping.
3. Removing and moving the parts:
 - After stamping, the robot must remove the two parts from the template and move them to the corresponding rail (left and right). The positioning of the robot must allow fluid and precise movement of the parts to avoid collisions or interruptions in the process.
4. Coordination with the Parts Counter:
 - The robot must be synchronized with the parts counter to ensure that the production process reaches the desired count. This may require integrating the robot with the hydraulic press control system or implementing communication between the devices.

5. Employee safety:
 - During all stages of the process, employee safety must be a priority. The positioning of the robot must ensure that there is no risk of collisions or accidents during interaction with the machine and parts.

We can start planning the ideal positioning of the robot at the workstation, considering the specific requirements for handling parts, interacting with the hydraulic press and moving parts after stamping. A carefully planned layout will ensure smooth integration of the robot into the existing production process.

GRIPS OR CLAMPS:

Taking into account the nature of the workpieces, the grip requirements and the working environment, and offering a secure and stable grip to guarantee the precision and efficiency of the handling process: the grips or clamps for gripping the workpieces, being metallic, oiled and weighing half a kilogram each, it is important to choose suitable grips or clamps that guarantee a secure and stable grip during the process. Here are some suggestions to consider:

1. Pneumatic or hydraulic grippers:
 - Pneumatic or hydraulic grippers can offer an adjustable clamping force, allowing a firm grip on metal parts. They are suitable for industrial environments and can be easily controlled to open and close the jaws as required.
2. Magnetic grippers:
 - Magnetic grippers can be an effective option for handling metal parts. They use powerful magnets to hold the parts, providing a strong and reliable grip, even on oiled surfaces. However, it is important to ensure that the parts are ferromagnetic so that they can be successfully manipulated.
3. Tweezers with anti-slip coating:
 - Tweezers with a non-slip coating can provide a secure grip on oiled surfaces. The anti-slip coating helps to increase friction between the gripper and the workpiece, reducing the risk of slipping or falling during handling.

4. Grippers with Vacuum Systems:
 - Tweezers equipped with vacuum systems can be effective for handling oiled metal parts. They create a strong suction that holds the part firmly while it is moved. These grippers are highly versatile and can be adapted to different part shapes and sizes.

WORKPIECE SUPPLY:

It is possible to program the system so that the robot handles parts according to different positioning sequences (handling parts based on their numbering). This type of programming logic is commonly used in industrial automation systems to deal with different production scenarios.

For example, we want to define a sequence of commands that instructs the robot to:

1. Remove parts 1 to 50 from a specific position.
2. Remove parts 51 to 100 from another position.
3. Continue this pattern until part 780.

This programming logic can be implemented using specific programming languages for robot control, such as ROS (Robot Operating System), or programming tools provided by the robot manufacturer.

By programming the system in this way, the aim is to optimize the parts handling process, ensuring efficient and organized distribution throughout production. This allows the robot greater flexibility and adaptability to deal with different production requirements and work sequences.

BI MANUAL:

Some suggestions for analyzing and overcoming the difficulty of replacing two human arms and loading in bi manual

1. Design the handling tool:
 - Develop a suitable manipulation tool that can mimic the action of the two human arms and press the buttons of the two-handed system. It can be designed with flexible or articulated arms to provide movements similar to those of human arms.

2. Force and touch sensors:
 - Install force and touch sensors in the manipulation tool to allow the collaborative robot to feel the pressure applied when pressing the buttons of the two-hand system. This will allow for more precise and safer interaction with the machine.
3. Programming Precise Movements:
 - Programmed the robot to perform precise, coordinated movements when pressing the buttons on the two-hand system. This may require the use of advanced motion control algorithms and precise calibration of the manipulation tool.
4. Adequate Training and Testing:
 - Carries out trial and error and extensive testing to ensure that the robot can perform the task safely and efficiently. This includes virtual simulations, bench tests and practical training in the production environment.
5. Continuous Monitoring and Adjustments:
 - Monitoring the robot during operation adjusting as necessary to optimize its efficiency and accuracy. This can involve calibrating sensors, improving control algorithms and adjusting movement programming.

Collaboration between engineers, programmers and machine operators will be essential to overcome technical challenges and ensure successful implementation.

3.12. Simulation and Testing

Simulation and Virtual Tests:

- In the first phase, after identifying the workstation and the productions (references) where the introduction of the technological innovation would begin, there was in-depth work by the laboratory team (external to the manufacturing organization and the cobot supplier) on virtual simulations in the desired application for implementation in the factory. Using robotics and automation simulation software, different scenarios were modelled to assess performance, identify bottlenecks and predict possible safety or efficiency problems. With the advantage of virtually testing interactions before implementing them in the factory, avoiding the use of unnecessary resources

and production stoppages for these tests and simulations. AI was/is also a valuable tool at this stage of the study. What was needed were:

- a) drawings of the parts, detailed and precise in each dimension, individual weight of each reference, identification of the surface finish in a real context;
- b) Follow-up in the factory in the form and procedure of production by the human collaborator;
- c) Observe and understand the space between tool, machine and parts, to build a functional gripper.
- d) Observing and understanding the different parts, geometrically different, that it would be important to function in the same gripper.
- e) Observe and understand the average productivity of human employees.
- f) Observe, understand and measure the handling space currently used, in order to convert it for cohabitation of cobot and human beings.
- g) Identify the physical flow of parts fed to the robot (contextualizing new benches, with precise positioning, as well as the same for the part, quantity of parts in their x, y, z coordinates).
- h) Identify the physical output flow of the part produced and possible constraints: the part not sliding, accumulating and causing a collision, quantity per container unit.

After concentrating synergies and bringing together all the points mentioned above, we obtained a dynamic and virtual simulation that seemed to convince us that the possibility of implementation was indeed real. Geissdoerfer et al., 2023. Moving on to building the gripper. Identified as the challenge of the project and of functionality and operability in a factory context. Multiple references, different weights, oiled parts, a 270° flow with the part (between the feed and its output in the container) and, with all these multiple and versatile possibilities, to be in harmony with the existing tools and machines, which until then had allowed us to produce without non-conformities and with the knowledge of the entire production, quality, technical and maintenance team. The gripper built will be a suction gripper, which, being for multiple references, has a larger set of elements, making it heavier than a single-function gripper. Another challenge is the balance of the robotic arm when it is

extended to its maximum capacity in length and angle. Evidence that leads us to think about a more solid structure to receive it and fix it in the working harbor.

There are two ways to go:

- Either one structure per workstation, or a multiple structure, removable (even for certain periods), to suit other workstations. The vision and outlook for the introduction of cobots is to extend to more jobs, and also to ensure that the same robot/robotic arm/cobot is reintegrated into various and versatile uses. That's why it's so important to have a solid, robust but removable base that allows us to be more dynamic in the factory, testing, simulating and analyzing possibilities for other productions and jobs that have also been identified as possible applications for the technology. And even to innovate, create and extend the range of production alternatives, both existing ones and new ones requested by the market.

Systems Integration Test:

- In the Systems Integration test phase, tests were carried out, first in the laboratory and then in the factory, to ensure that cobot integrates correctly with other factory automation systems and processes. In the factory, close to the workstation, in the context of working and cohabiting with production and the team, a test area was prepared with parts from the same supply as the current production, to test the gripper, the positioning of the arm coordinates, to become aware of the real physical space required, to keep the surrounding workstations and the lifting and handling equipment working. Above all, for the initialisation of a new element, the cobot, with different mobility to the usual (traditional machines), in a day-to-day situation where until then any technology only reacted to a command and with specific and unique movements.
- There are taboos to demystify, new realities to grasp, understanding of the emerging needs of the markets and not forgetting that in the current and real conditions proposed, we must keep the flow of supply to the customer intact and fluid.

The next step included synchronising cobot with existing systems (machines, controllers and operator interfaces).

Safety tests and standards:

- Even during the first tests, in a reserved place and then at the workstation itself, potential risk areas where human interaction with the robot may occur were identified, such as work zones and robot movement zones. While testing the limits of action of the robotic arm, physical limits were set for the smooth movement of the human, without the possibility of collision and the flow of parts. A suitable emergency exit corridor was defined, while the ergonomics of the workstation were adjusted to guarantee the fluidity of human movements, with a focus on improving working conditions for employees. There was an intensive practical training phase in which employees had direct contact with the robot, receiving practical examples and detailed instructions on how to operate the cobot. This ensured that everyone was familiarized with the equipment's operation and movements, promoting a smooth and safe transition. Forces and speeds were tested and defined when moving from coordinate to coordinate, as well as the robot's return to zero point, so that if a collision occurs due to human distraction, the risk and impact on the employee's health is reduced. Preparing the space, avoiding blind spots in the field of vision of all employees. Ensuring that the support benches are identified as well as the limits of interaction between robot and worker. Consistency and reinforcement of the 7'S concepts. Good lighting in the space. Intermittent signalling indicating the robot is operating. Tests with the lowest speed and force until reaching what was collectively understood to be the limit for everyone's safety. Including the robot itself.
- In short, to provide a safe, calm environment, free of fears or pressures about the unknown. Exemplified and demonstrated in real time, the movement of the robot's complete cycle, to avoid surprise effects.

Comparison between Simulation and Reality:

- The biggest divergence found between the theoretical concept and reality is that changing and re-adapting the cobot to a new workstation is simple and within everyone's reach. In fact, even if we program by imitating human movements, we only do so in macro terms. Because in the end, the coordinates must be precise and their sequence, as well as the speed/force between points. And this phase of programming requires a predisposition to understand programming concepts, even if they are basic and from the user's point of view. However, this doesn't completely prevent you from doing it. With

consistent training, dedication and focus, it is possible to overcome the difficulties. The main limitation we faced was keeping the workstation in operation while meeting the deadlines of the order lines on time and managing to gain safety stock, with increased demand for the references in question, to make room for implementing cobot in a consolidated and stable way.

- Scheduling and the pace of productivity were adjusted during periods of plant closures, taking advantage of scheduled stoppages to make precise adjustments to the cobot without interfering with regular production. In addition, we anticipated requesting consumption forecasts from our client, which allowed us to identify the ideal time to implement the cobot without causing abrupt stock shortages or the risk of delivery deadlines not being met. For example, during the adjustments, we realized that the programmed speed for moving between points was slightly higher than necessary, which caused slight misalignments in the lighter parts. By adjusting the sequence and speed in the software, we were able to optimize the process, keeping production in line with the required standards and without affecting deadlines. This adaptation not only made it possible to avoid wasting time and material, but also increased the efficiency of the production line during the testing phase, without jeopardizing stocks or on-time delivery.

Team feedback during the tests:

- There were extremes of reactions: from unconditional supporters, to the curious, to the resistant and the completely discredited, discrediting themselves and their actions.
- With ages ranging from 20 to 63, life's journey and experience influence receptivity, interaction and reaction to innovation and paradigm shifts. The approach is important to be strategic, contagious and in convoy.
- In order to deal with the most resistant and skeptical reactions within the team, there was a year-long preparation process, in stages and supported by the Production Department's latest strategic plan for 2024. This plan included practical workshops and detailed demonstrations of cobot's functionality, with a focus on reducing fear of the unknown and promoting confidence in using the new technology. For example, one of the more resistant employees initially expressed concerns about the complexity of the operation and the possibility of job losses. By getting him directly involved in practical tests and

simulations, we showed him how cobot could be a support tool, not a replacement, and how it could make his day-to-day life easier, elevating him to the level of controller of cobot itself and of product quality, downstream and upstream.

- Over time, this employee became one of the biggest advocates of the implementation, realizing the benefits in terms of reducing repetitive efforts and the possibility of redirecting his attention to more strategic tasks. This success story was an important catalyst for influencing other employees, creating a domino effect that gradually led to the acceptance of the technology by most of the team.

Purpose of the simulation:

- With the simulation we were able to test the integration of the collaborative robot with the press, ensuring that there is an efficient synergy between the machine, cobot and operators. It was also possible to predict communication failures, identify non-conformities and optimise the workflow before the physical implementation of the robot. We felt that the initial benches were basic, but essential for understanding the initial difficulties and realising the need for robust benches dedicated to the project. From the first difficulties observed with the benches, it became clear that delving deeper into programming and defining the coordinates would be essential. This ensured that the robot could feed on stacks of correctly stacked, aligned and positioned parts, rather than working with a single unitary part, as at the beginning.
- The Lean concept also showed the need to be more ingrained in the company's culture, rather than just applied in isolated moments. The tests allowed us to measure the impact of the cobot on the product's cycle time, which was initially slower due to the fear of using excessive force and for safety reasons. With trust being built on a daily basis, cobot is expected to reach or even surpass human productivity. With an estimated ROI of 12 months, the adjustments made in the simulation, such as optimising response times and improving coordination between the robot and operators, are fundamental to achieving these goals. For example, after adjusting the gripper's force and precision, we were able to reduce the cycle time by 50 per cent, increasing the efficiency of the process.
- The main advantage observed was the recognition of the importance of retraining operators, who began to interact virtually with the cobot,

understanding its operation and limits. The internal training plan allows for gradual and efficient adaptation, with higher returns compared to external training, while respecting individual time and capabilities. Obviously, there is always a communication channel with the outside world, which at this point is the author of the work.

Integrating Feedback into the Continuous Improvement Cycle:

- The feedback obtained in the real tests was fundamental to adjusting the robot's control algorithm, with support from the supplier company at key implementation moments. These adjustments allowed for continuous improvements in human-machine interaction and in the production layout, carried out between each production cycle within the kanban system.

3.13. Pilot Implementation

The simulation made it possible to test the integration of the cobot with the press, identify faults and optimize processes before physical implementation, ensuring greater efficiency and safety in the factory environment.

1. Pilot objectives

Verification in a real environment: implementation in the pilot plant is essential in order to detect faults, adapt the system and adjust the cobot's behavior in a real environment. More importantly, to understand the implementation lead time, the various stages, the need to allocate production and technical resources, minimizing system integration stoppages, keeping the production process in and the delivery plan in fulfilment.

One of the assumptions of the implementation policy of the new expansion technology/innovation, this implementation phase at the pilot plant is crucial for defining and planning the jobs to be targeted by this innovation to be targeted by this innovation. Kjaer et al., 2022,.

Another important point that we have achieved at this stage is to identify with greater certainty which machines we might be able to adapt to receive the new technology.

As well as the possibility of maintaining or even improving the flow and optimization of the layout.

New investments from scratch and an increase in physical space may be too costly and can only be realized with capital. Therefore, throughout the project plan, the assumptions were and are that all the existing machines and tools are in the same physical space. We can always improve, be creative, innovate, optimize, but start from what exists and with resources internal teams as a rule.

At the time of writing, the implementation phase is still underway. The objectives of the pilot project have been defined, we validate day after day that the results expected from the simulations can be achieved in real production conditions, at different and slower rates than imagined, but consistent. With planning, strategy, synergy of energies and a lot of collective involvement from the entire organizational tree.

Minimizing Risks: As we have already possible, in this pilot phase, to conclude that it allows us to identify problems that could be critical if not detected in advance, such as production stoppages, product non-conformities and reduce the risks of a complete implementation and expansion as intended.

2. Selection of the Pilot Environment

Controlled Environment vs. Production Line: the choice of the environment where the pilot is being implemented, a controlled environment within the factory, has two factories, has two analyses in common with the vision of expansion, in the first phase: kanban production, long production runs and repetitive, simple tasks. The choice is justified in terms of the complexity of integration with basic machinery systems, where safety is reinforced with strong the Lean concept and with a 50 per cent share of the production of the final process of the sheet metal cutting and forming section.

3. Comparison between Simulation and Real Implementation

The simulation phase proved to be a crucial step in the integration of the cobot with the hydraulic press, enabling us to identify potential faults and optimize the processes before the physical deployment. By simulating different scenarios, we were able to enhance both the efficiency and safety of the system, ensuring that, when transferred

to the real factory environment, the cobot could work under safer conditions with optimized performance.

In the pilot phase, however, the implementation pace was slower than anticipated. Despite this, the key objectives of the simulation—fault detection, process adaptation, and safety improvement—were fully met. The real-world environment revealed additional complexities, such as adjustments required in the system's operation and the allocation of resources, which weren't as apparent during the simulation. While these challenges slowed the process, they were invaluable for identifying critical areas for improvement and ensuring that the integration could proceed without jeopardizing production continuity.

One of the most important lessons learned during the pilot was related to the lead time of implementation. We realized that the staging of production and the reallocation of technical and production resources required more precise coordination than initially predicted. This allowed us to minimize integration-related stoppages and maintain our production delivery schedules. Although slower, the process has been consistently advancing towards the expected results outlined in the simulation.

Another vital aspect highlighted in the real environment was the evaluation of machine compatibility. Through the pilot, we were able to assess which machines were best suited for future adaptation to the cobot technology. The simulation had laid the groundwork, but the pilot confirmed the adaptability of several machines, opening opportunities for layout optimization and process flow improvement without needing significant new investments or additional physical space.

In conclusion, although the simulation provided a reliable foundation for the cobot implementation, the real-world pilot exposed challenges that were not fully captured in the virtual model, particularly regarding the pace of integration and the allocation of resources. These insights are crucial as we proceed with the project, ensuring that the final rollout will be efficient, safe, and aligned with the company's production goals.

CHAPTER IV - DISCUSSION

4.1. Analysis of Results

The implementation of the cobot on the production line showed promising results, supported by the simulations and tests carried out. Analyzing the interactions between the robot and the hydraulic press, combined with ergonomic and safety assessments, made it possible to identify challenges and practical solutions for efficient integration. Virtual tests were key to minimizing the risk of downtime and waste, while the working environment was adjusted to optimize the flow of parts and the interaction between humans and machines. Machado et al., 2022. During the implementation phase, adjustments to cobot programming ensured precision in movements, resulting in a 50 per cent reduction in cycle time and a significant increase in process efficiency.

4.2. Benefits and Challenges

The main benefits of introducing the cobot include an increase in productivity, with an estimated return on investment (ROI) of 12 months, and a reduction in the operators' repetitive workload, allowing them to focus on more strategic tasks. In addition, practical interaction and ongoing training have favored acceptance of the robot among employees. However, some challenges remain, such as the need for a suitable gripper design to handle parts of different shapes and weights, as well as adapting the operators to the new technology. Initial resistance was overcome through an effective training process and practical demonstrations, emphasizing the robot as a support tool, not a substitute. Ruijer, 2021.

4.3. Comparison with Previous Studies

The comparison between the results obtained and previous studies reveals an evolution in the integration of cobots in production environments. McGowan et al., 2023. While previous research highlighted the challenges of adaptation and acceptance by workers, this project has shown that, with the right support and training, the transition to using cobots can be carried out successfully. The ability to carry out virtual simulations in advance and utilize real-time test feedback provided a significant advance in operational efficiency. Adapting the cobot to interact with a manual two-arm system, for example, not only broadened technical understanding, but also fostered a collaborative environment between operators and machines.

Conclusion

The implementation of cobot in the factory, based on simulations and the collaborative work of the whole team, is underway and looks promising. Adapting cobot to the real needs of the working environment is an essential step towards optimizing productivity and efficiency, while preserving the quality and safety of processes.

Lessons learned and best practices:

Leadership skills, technological innovation and process optimization. Some suggestions for the ongoing process and the expansion policy:

1. Implementation of Artificial Intelligence (AI) and Machine Learning (ML)

- Use of algorithms to optimize the operation of cobots, predicting failures and adjusting parameters in real time.
- Benefits: Improved operational efficiency, reduced downtime, predictive maintenance and increased productivity.
- Application example: Using sensors and historical data to predict when a press will need maintenance, reducing unplanned interruptions.

2. Integration of the Internet of Things (IoT)

- Develop an even wider network of IoT devices to collect real-time data from presses and cobots, integrating this data into a central platform for monitoring and analysis.
- Benefits: Improved visibility of processes, ability to make decisions based on data, increased safety and efficiency.
- Application example: Continuous monitoring of the performance of presses and cobots, with automatic alerts to operators in the event of anomalies.

3. Development of an Integrated Management System

- Description: Suggestion to create a management system that integrates the operation of the cobots with other business systems, such as ERP (Enterprise Resource Planning), MES (Manufacturing Execution Systems) and DPP (Development and Prototyping Phase).

- Benefits: Optimization of resources, better production planning, reduction of waste and increased coordination between departments (prototyping and testing phase).
- Application example: Integration of production data with the ERP system for automatic adjustment of raw material orders according to demand (planned for 2026).

4. Focus on Sustainability

- Description: Incorporating sustainable practices into the operation of cobots and presses, such as optimizing energy consumption and minimizing waste. (The organization already has a photovoltaic network to support this phase of technological innovation, in addition to all manufacturing activity).
- Benefits: Reduced operating costs, compliance with environmental regulations, improved company image.
- Example of application: Implementation of kinetic energy recovery systems in the presses, use of recyclable materials and reduction of waste (in the study phase for implementation simulation).

5. Development of a Training and Capacity Building Program

Description: Create a comprehensive training program for operators and managers, focused on the use of cobots and the new technologies implemented (in the development phase at the top of the organizational tree). Benefits: Improved team skills reduced operational errors, greater safety and efficiency. Example of application: Workshops, practical training with videos on the operation and maintenance of cobots and associated systems.

CHAPTER 5 - CONCLUSIONS AND FUTURE DEVELOPMENTS

In conclusion, the exploration of collaborative robots (Cobots) within the context of emerging technologies presents a fascinating paradigm that shifts in the landscape of human-robot interaction. The objectives align with the overarching goals of efficiency, effectiveness, and competitiveness, reflecting the ongoing pursuit of a harmonious balance between technology and human capital.

The macro structural advantages highlight the careful integration of collaborative robots into existing work environments, emphasizing safety, flexibility, and minimal disruption to established workflows. Differentiation factors, such as autonomous relocation capabilities, safety systems, and educational applications, underscore the unique and multifaceted potential of collaborative robots across various industries.

In essence, collaborative robots not only represent a technological breakthrough but also signify a harmonious collaboration between human ingenuity and machine capabilities. As industries continue to embrace these innovations, it becomes evident that the strategic integration of cobots is a key driver for progress. This offers a glimpse into a future where humans and robots work together seamlessly to achieve unprecedented levels of productivity and efficiency.

The imperative for individuals to adapt and thrive in this technologically advancing world is clear, making strategic planning and awareness crucial for successfully navigating this dynamic landscape.

Study Contributions

Here are some theoretical and practical contributions that can be suggested from the realization of the study and project on the integration of cobots in the context of industrial management engineering:

Theoretical Contributions

1. Development of Integration Models:

Creation of theoretical models for the integration of cobots in industrial environments, addressing not only the technical part, but also social and organizational aspects, facilitating acceptance by workers.

2. Concept of Industry 5.0:

Contribution to the discussion on Industry 5.0, which focuses on collaboration between humans and machines, highlighting the importance of personalization and sustainability in industrial production.

3. Ergonomics and Safety:

Advances in understanding the ergonomic impacts of collaborative automation, with an emphasis on safety in the workplace and minimizing work-related injuries.

4. Multidisciplinary approaches:

Encouraging interdisciplinary approaches, integrating concepts from engineering, organizational psychology and social sciences to better understand the dynamics of human-robot interaction.

Industrial Contributions

Practical Contributions

1. Operational efficiency:

Practical demonstration of how implementing cobots can increase operational efficiency, reducing cycle time and improving productivity on production lines.

2. Cost Reduction:

Concrete proof that collaborative automation can lead to a significant reduction in operating costs by minimizing waste and optimizing the use of resources.

3. Capacity building and training:

Development of effective training programs for workers, which not only increase the acceptance of cobots, but also improve the overall competence of the workforce.

4. Sustainability:

Implementing sustainable practices in industrial operations, showing how automation can be aligned with green initiatives such as energy recovery and the use of recyclable materials.

5. Case Studies and Best Practices:

Creation of case studies documenting practical experience in implementing cobots, serving as a valuable resource for other companies wishing to follow a similar path.

6. Technological Innovation:

Promoting innovation through the adoption of emerging technologies, such as IoT and AI, which can be integrated into cobots to improve monitoring and predictive maintenance, Varela, Lima & Sousa, 2023.

These contributions can help shape academic research and industrial practices, strengthening the position of industrial management engineering in the European market and highlighting the relevance of cobots in transforming industrial operations.

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