Oliveira, Carolina
Pereira, Filipe
Rocha, António

Implementation process of collaborative robots (Cobots) in an automotive technology supplier company

http://hdl.handle.net/11067/7397
https://doi.org/10.34628/X6YA-5Y79

Metadados

Data de Publicação 2023

Resumo Progressively, the industry is choosing to purchase automated systems or modify existing ones to produce a wide range of components. With robotics and industry constantly evolving, it is essencial to manage the implementation process to ensure maximum safety and efficiency. With this aim, an electronic components production line and its workstations have been analyzed, through the observation of the production processes and the examination of relevant documents. A variety of analytical tools and...

Tipo bookPart

Editora Universidade Lusíada Editora

Implementation process of collaborative robots (Cobots) in an automotive technology supplier company

DOI: https://doi.org/10.34628/X6YA-5Y79

Carolina Oliveira*, Filipe Pereira[2], António Rocha[3]

[1] University of Minho, Department of Production Systems,
Campus de Azurém, Guimarães, Portugal
anacarolina9482@gmail.com

[2] Polytechnical Institute of Cávado and Ave, School of Technology
Vila Frescainha, Barcelos, Portugal
fpereira@ipca.pt

[3] Polytechnical Institute of Cávado and Ave, School of Technology
2Ai – Applied Artificial Intelligence Laboratory
Vila Frescainha, Barcelos, Portugal
arocha@ipca.pt

Abstract. Progressively, the industry is choosing to purchase automated systems or modify existing ones to produce a wide range of components. With robotics and industry constantly evolving, it is essencial to manage the implementation process to ensure maximum safety and efficiency. With this aim, an electronic components production line and its workstations have been analyzed, through the observation of the production processes and the examination of relevant documents. A variety of analytical tools and methodologies were used to identify the most critical and least ergonomic workstation, and to improve its efficiency, a collaborative robot has been proposed. This article outlines the steps taken in automating the station, including the design of

* Corresponding author

the robotic cell and preparation of a comprehensive business plan, it also, outlines the requirements for a functional robotic cell and aims to understand the necessary investment for effective and efficient cell automation. Upon completion, the company will save six employees per day and free up 64% of available time, with a projected saving of 503.697,00€ in labor costs over five years of investment.

Keywords: Cobot; Automation; Process; Infotainment; Lean production.

1. Introduction

This project was conducted in an automotive technology supplier company that provides advanced safety, electrification, and autonomous systems, including radios and driving assistance systems. The research work aims to improve a manufacturing line, studying the viability of incorporating collaborative robots to reduce operating costs, extend equipment life to optimize production efficiency by identifying and eliminating waste and inefficiencies throughout the production system life cycle (Singh, J. and Singh, H., 2015). This can be achieved through the active participation of employees at all levels of the operational hierarchy (Singh, J. and Singh, H., 2015), and this is what is expected from the implementation of this project, to determine whether the implementation of cobots are a good investment decision to improve a manufacturing line.

Since an organization's ability to grow is closely tied to its ability to change and adapt to new technologies, it's crucial to establish a process for incorporating automated systems. A company's ongoing growth and the need for flexible production lines create a constant need to optimize factory space and resources. The primary objective of this study was to reduce the labor force, leading to less handling and improved responsiveness to workstation requirements. Several tools were employed to examine the current state of the production process and conduct a critical analysis, allowing for the development of a model to automate a workstation that is adaptable to various conditions.

The implementation of a collaborative robot (cobot) in the firmware requires investigating technological developments and studying the relevant process. To ensure successful implementation, it is important to: 1) Conduct a strategic analysis of the project, 2) Calculate the system's efficiency, 3) Evaluate the economic feasibility of the project, 4) Assess the ergonomics of the workstation, 5) Define the implementation phases, 6) Study the cycle times, 7) Use a decision-making method, 8) Write a statement of work, and 9) Design the robot cell.

The production processes of the assembly line and the corresponding flow of materials were studied, along with the cycle times of each workstation and the incorporated poka-yoke mechanisms. This was achieved through constant observation of the shop floor and document analysis. Then, the cycle times between different workstations were compared, the variation of product demand was analyzed together with the installed capacity, and an ergonomic evaluation of the workstation was conducted.

The article is structured into five sections. The first section, "Introduction," outlines the research objectives. The second section, "State of the Art Review," provides a background on lean manufacturing, automation, and robotics. The third section, "Description and Critical Analysis of the Current State," describes the current state of the assembly line. The fourth section, "Cobot Implementation," outlines the steps for properly implementing the cobot. The fifth section, "Conclusion and Discussion," summarizes the research outcomes.

2. State-of-art review

2.1. System integration

The integration of an automation system can turn an idea into a fully functional system. Ensuring a safe integration requires studying the connection between the system, its environment, and humans. Those who interact with the automation system must receive training on how to handle different situations and operate it under normal conditions. The SIMBIOSIS model, introduced by Kearsley (Kearsley, 1982), outlines the role of humans in a robotics system and helps optimize work performance. This model guides the integration planning of a robotic system by considering workplace design, working environment, training, safety, and control (Mohammad Rajabalinejad, 2020). The elements included in the system are products, processes, procedures, information, techniques, facilities, and services. The system can be decomposed into subsystems to assign tasks to different departments, facilitating the integration of a new system (Nof, 1999). The environment is defined as the parameters that influence or are influenced by the system of interest at any stage of its life cycle (Nof, 1999).

2.2. Automation and lean robotics

In Industry 4.0, the use of automated and robotized solutions is essencial for optimizing activities. Companies must keep up with the increasing industrial challenges and equip themselves with the tools and experts necessary to meet current requirements such as customer demands, quick response times, and high quality. The traditional supply chain is evolving, as is the relationship between humans and robots. (Michael Rüßmann, 2015).

The concept of lean robotics focuses on enhancing the connection between delivering customer value and leveraging robot technology for better results. As stated by Samuel Bouchard (Bouchard, 2017), it is important to treat robot cells in the same way as other shop floor operations. To aid in this integration, he created a guidebook titled "Lean Robotics: A Guide to Making Robots Work in Your Factory". This guidebook explains how robots can impact lean production efforts and highlights the benefits of integrating them, such as improved product quality, elimination of ergonomic issues, time savings, prevention of health and safety problems for employees, error prevention and detection, and utilizing human potential to its full potential.

According to Bouchard (2017), there are four fundamental principles for the correct functioning of a lean robotic cell:

1. People before Robots: This principle is governed by two aspects: "(A) Robotic cells should be safe for humans; (B) Robots should be usable tools for everyone."
2. Focus on the Output of the Robot Cell: The robot cell should contain only the tools needed to create value for the customer.
3. Waste Minimization: No process is 100% efficient, but the application of lean methodologies to identify waste allows us to combat it. Lean Robotics defines the wastefulness of human potential as the eighth waste.
4. Leverage Your Capabilities: To continuously develop the necessary capabilities to meet the needs of robotic cells, it is important to assess the long-term potential of their applicability and find the right balance between costs and benefits.

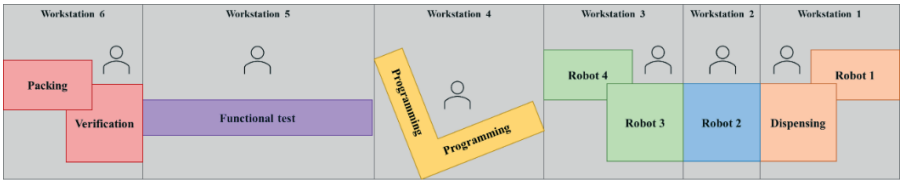
Lean Robotics promotes the implementation of robotic solutions while still considering other production needs (Bouchard, 2017).

3. Description and critical analysis of the current state

The primary objective of the project is to automate a workstation, to achieve this, it is crucial to examine the standard procedures for the different operations that occur. The first step was to observe the workers firsthand and comprehend their roles, from the value-adding functions to any redundancies.

By monitoring the assembly line on a daily basis, we were able to group the tasks at each operator's station, resulting in the creation of six workstations with unique characteristics. (Figure 1).

Figure 1: Final assembly workstations



3.1. Description of the material flow through the workstations

Before entering the assembly line, some components must undergo different levels of transformation in various production areas. The material flow starts in the warehouse, which serves as the source for feeding production needs through material distribution. The initial step involves scheduling the Integrated Circuits (ICs) and marking the Quick Response code (QR code) on the boards offline. After gaining identity, the ICs and boards move to the SMT zone, where the A and B boards are assembled with various components. They then proceed to the ICT zone for short circuit checks, after which the need for transport with the aid of edges ends. The boards are then singulated in the Milling process. The final process before the final assembly is the screwing of metallic components to the B board in the Sub-assembly stations. Finally, the finished A and B boards are stored in a support supermarket for the final assembly lines, where they are displayed based on their part numbers for matching.

3.2. Final assembly stations

Due to the project's focus on the final assembly area, a more in-depth analysis was needed. The line was divided into four sections: manual final assembly, programming, functional testing, and packaging. Posts 1, 2, and 3 were part of the manual final assembly area, post 4 belonged to the programming area, and posts 5 and 6 were in the functional testing and packaging areas, respectively. To understand the entire area, it was necessary to be familiar with all the functions of each workstation and the current poke yoke systems. To simplify the study of product X's production process, a flowchart was created and is shown in Figure 2.

Figure 2: Final assembly flow chart

The operators cycle times (CT operator) and machine cycle time (CT Machine) were surveyed to understand the time taken at each stage of the process. The results are

presented in Figure 3, which shows the cycle time between the operator and machine for each workstation. This information helps to identify bottlenecks in the process and opportunities for improvement. By analyzing the cycle times, it becomes possible to identify areas where automation can help to increase efficiency and reduce waste.

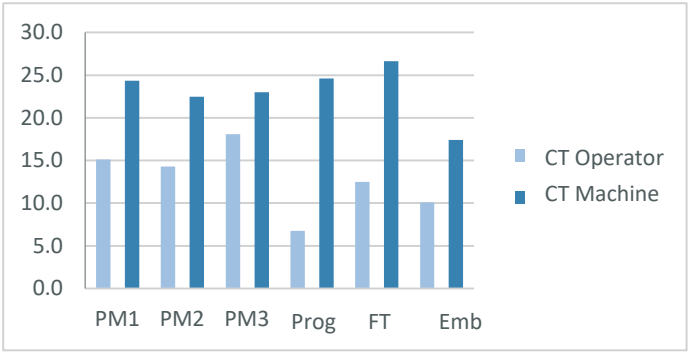


Figure 3: Final assembly cycle times

The cycle times of the machines were recorded by taking into consideration the handling time, which refers to the time needed to place and remove a device. To make the operator's job easier and keep the conveyor clear at the programming station, waiting racks were deemed essential due to several factors such as the execution of diverse movements, the large distance between testing spaces, and the long testing time. As a result, the time the operator spends placing radios in these racks is not included in the test cycle time. The functional test cycle time includes an additional 2 seconds for handling, which refers to the time it takes the operator to remove a tested radio and place another one for testing. The cycle time for each station in the programming station and functional test was calculated by dividing the total test time for a machine by the number of machines available on the line.

3.3. Bottleneck analysis and volume forecasting

Initially, automating the functional test station was considered as it was identified as the bottleneck station. However, the required changes in the layout would be substantial and the solution too complex. To address this issue and to balance the cycle times of the workstations, it was deemed sufficient to invest in an additional testing system, setting the CT of this station to 24.6s.

Evaluating the times presented in Figure 3 showed that the operator CT at the programming station was significantly lower compared to the machine CT, with an op-

erator utilization rate of only 36%. As the assembly line operates in tandem with another identical line and runs for three shifts, replacing these operators with a cobot would result in saving 6 operators per day. While eliminating this inefficiency would be beneficial, it is necessary to assess the demand forecast for the next three years and verify if the investment amount can be amortized. Through an ABC analysis of the demand forecast for the current year and the next two years, it was established that product X will be the high-volume production item for the coming years.

4. Cobot implementation

The project was prepared by the Industrial Engineering department as a continuous improvement measure with the aim of implementing two cobots. By using a system integrator, the company was able to reduce the number of employees required for the production of product X, releasing a total of 6 people (1 per line per shift x 2 lines x 3 shifts). The success of the project can be measured by the savings in labor, and considering the investment cost in cobots, it is expected to have a return on investment in two years. To achieve these goals, the company provided the best training for the necessary employees and access to detailed manuals for maintenance and engineering. It was also essential to clearly define the Statement of Work (SOW) to obtain the necessary approvals. This project represents a huge step towards Industry 4.0 and is expected to be used as a model for future improvements. It will put the company in a favorable position and drive better results, thanks to the company's focus on constant improvement and years of experience. The acquisition of the robots was planned for six months after the project's initiation, with a one-year follow-up by the integrator.

4.1. Project framework

Once the concept was established, a plan was devised to implement the solution, covering everything from defining the project to putting the robot into use. It is important to remember that solutions can evolve during the planning phase, so it's necessary to tackle multiple tasks simultaneously and set clear objectives during each stage of the project.

The project definition stage is divided into two phases - Preparation and Design - and this second phase matches several fundamental topics including, manual cell mapping and layout, mapping and layout of the robotic cell, manual work vs robot work, to devise the project concept.

In the preparation stage, the initial tasks involved organizing the responsibilities for each party involved in the project. After thorough brainstorming and considering the

limitations and advantages, the integrating company was able to provide a budget estimate, allowing the project team to develop a comprehensive business plan (Carvalho, 2008).

In the planning stage, a thorough analysis was conducted to evaluate the impact on key performance indicators (KPIs) such as labor productivity, efficiency, and production rate. The analysis revealed that the indicators related to the number of employees would change, and the current forecast predicts a 4.26 unit increase in productivity per man-hour.

In the design stage, it is important to outline the concepts of manual and robotic cells to later compare and define the components of the robotic cell. The components of the robotic cell are defined as: (1) the robot, (2) the tool, (3) the platform, (4) the sensors, (5) the safety measures, and (6) the software. The manual cell was defined based on observations of the assembly line and information collected during the current situation description phase. The definition of the robotic cell emerged during discussions with various integrators. At this stage of the project, it was essential to present a proposed layout for the cell and describe the tasks the robot would perform.

By comparing the manual and robotic cells, the advantages and disadvantages of each approach were assessed:

1. Customer identification: Both solutions meet the customer's needs without the need for intermediate steps (FT station).
2. Output definition: The output equipment supplied to the customer will be the same, but a bottom conveyor must be added to the output conveyor to allow for device analysis.
3. Input definition: The robot can maneuver the apparatus, but a guide must be placed on the input conveyor to allow for easier part presentation. The work of the PM3 operator remains unchanged.
4. Process description: The steps performed by the robot will differ from those performed by the operator. The robot considers the conveyor capacity and can only place the device in the required position. It is recommended to maneuver the devices with caution and not pile them up when transporting them to the output conveyor. The cobot can only pick up one device at a time, making it easier to ensure product quality.
5. Information flow: The absence of changeovers reduces the need for direct system interaction as the metrics remain unchanged. Information flow between the cobot and programming slots must be allowed.
6. Layout changes: Only the position of the MOLs must be changed, saving $1m^2$.

Given that much of the work was performed by an external team, it was necessary to agree on terms of purchase and collaboration. Requirements for device validation were defined, such as pre-acceptance of the equipment at the integrator with representative production samples agreed upon with the company. After different integrators provided quotations, a solution was selected using a method similar to the Analytical Hierarchical Process (AHP) to rank the parameters based on their importance to the solution (Leal, 2020); (Saaty, 2005). The system integrator team was responsible for proposing the remaining components of the robotic cell after the first component was chosen. A multi-faceted team consisting of the Current Product Engineer, the Fixtures and Projects Engineer, and the Quality Product Manager was involved to ensure customer requirements and product quality were met.

4.2. Business plan

A forecast for the return on investment (ROI) was created, considering factors such as production volume, investment cost, labor savings, savings from increased shop floor efficiency, and machine utilization hours in each year (Soares, Pinho, Couto, & Moreira, 2015). These factors were analyzed and compiled into Table 1, when summing the five years annual labor saving it is possible to obtain a saving of 503.697,00€.

Table 1. Forecast of earnings and costs over 5 years

Years	Investment	Production volumes	Labor Savings	Shop floor savings	Machine-hours cost
0	157 670				
1 (july)		1 137 900	47 497	50	9 957
2		1 557 701	132 097	100	27 260
3		1 180 575	101 913	100	20 660
4		1 085 443	95 296	100	18 995
5		1 420 993	126 894	100	24 867

The discounted cash flow and net present value (NPV) methodologies have been employed to evaluate the investment's profitability and determine its impact on creating value and wealth for the workstation and the company (Table 2).

Table 2. Calculation of the accumulated discounted cash flow

Years	Invest.	Earnings	Costs	Cash flow	$\frac{1}{(1+i)^t}$	Discounted cash flows	Accumulated discounted cash flows
0	157 670			- 157 670	1,0000	- 157 670	- 157 670
1		47 547	9 957	37 591	0,7506	28 216	-129 454
2		132 197	27 260	104 937	0,5634	59 122	-70 332
3		102 013	20 660	186 290	0,4229	78 782	8 450
4		95 396	18 995	262 691	0,3174	83 378	91 828
5		126 994	24 867	364 818	0,2382	86 900	178 728

Through the analysis, it can be concluded that the project presents a positive NPV, indicating that the investment is profitable and generates a surplus that can increase the wealth of the investor. The use of the Adjusted Payback Period of Invested Capital (PRCA) model also helped to determine the payback period of the invested capital, taking into account the time value of money (Table 3).

Table 3. Break-even point analysis

Ano	Cash flow	Discounted coefficients	Discounted global Cash-flows global	Discounted cumulative global Cash-flows global	
0	-157 670	1	- 157 670	- 157 670	-
1	37 591	0,7506	28 216	-129454	-
2	104 937	0,5634	59 122	-70332	-
3	186 290	0,4229	78 782	8450	0,8927
4	262 691	0,3174	83378	91828	0,1013
5	364 818	0,2382	86900	178728	1,0567

The investment is expected to be recouped within 2 years and 11 months, assuming that the production volume and the estimated savings remain constant over the period. The break-even point analysis can provide valuable insights into the viability of an investment and help to determine the minimum production volume necessary to cover the costs and start generating profits. It is an important tool for decision-making and helps to assess the financial feasibility of a project.

The results obtained from the analysis of the financial indicators support the implementation of the project and demonstrate its potential for generating value and benefits for the workstation and the company as a whole.

5. Conclusion

Initially, the study focused on the productive areas of the organization, specifically the production lines related to the project. Through daily observations of work processes, it was determined that the programming station was the best candidate for automation due to its high rate of employee downtime (64%). The results of the ergonomic analysis also showed the need for improvements to ensure the health and safety of workers. Analysis of the previous year's production volume of product X, along with volume forecasts for the coming year, also indicated that improvements to the workstations would increase overall productivity. Alternative improvement options, including the adoption of cobots, were considered and studied.

A project work-breakdown was conducted to develop a robotic cell, and once the concept design was established, it became clear that further details were necessary to assess the feasibility of an investment of 157.670,00€. A discounted cash-flow analysis was performed, leading to the conclusion that investing in a cobot was a safe choice with promising returns.

The implementation of the cobot in the production line will be entrusted to a specialized robotics integrator, providing a safer and more reliable approach as they have access to the technical and practical skills necessary for a robust installation in a shorter timeframe.

The adoption of the cobot is expected to result in labor savings of 503.697,00€ over the course of five years. This project's success will demonstrate a commitment to future automation initiatives, continuously improving the efficiency and effectiveness of the production line workstations and enhancing the overall quality of the manufactured products.

References

1. Bouchard, S. (2017). Lean Robotics: A Guide to Making Robots Work In Your Factory. Kindle.
2. Kearsley, H. M. (1982). Robotics and Human Factors: Current Status and Future Prospects. *Human Factors, 24*(5), pp. 535–552. doi: 10.1177/001872088202400504.
3. Leal, E. (2020). AHP-express: A simplified version of the analytical hierarchy process method. *MethodsX 2020:7:100748.* doi: 10.1016/j.mex.2019.11.021.
4. Michael Rüßmann, M. L. (2015, april 9). Retrieved from BGG: https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries.

5. Mohammad Rajabalinejad, L. v. (2020). Systems integration theory and fundamentals. *Safety and Reliability, 39:1*, pp. 83-113. doi: 10.1080/09617353.2020.1712918.

6. Nof, S. Y. (1999). Handbook of Industrial Robotics. Canada: *John Wiley & Sons, Inc.*

7. Saaty. (2005). The Analytic Hierarchy and Analytic Network Process for the measurement of intangible criteria and for decision-making. *IN.* Ehrgott M., Figueira, J., Greco S., 2005. Multiple criteria decision analysis: State of the art surveys. *Springer's I.*

8. Simões, R. M. (2015). Análise e Avaliação de Tarefas de Movimentação Manual de Cargas. *Universidade Nova de Lisboa, Faculdade de Ciências e Tecnologia*. Lisboa: Nova de Lisboa.

9. Singh, J. and Singh, H. (2015). Continuous improvement philosophy – literature review and directions. *Benchmarking: An International Journal, 22*(1), pp. 75-119. doi: 10.1108/BIJ-06-2012-0038.

10. Soares, I., Pinho, C., Couto, J., & Moreira, J. (2015). Decisões de Investimento. Análise Financeira de Projetos. *Edições Sílabo.* 4ª Edição. ISBN: 978-972-618-806-3.