Pick-and-Place Robotics Implementation Under the Influence of Lean Manufacturing – A Process Model

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Abstract. The article seeks to develop a process model to guide research and practice in the effective integration of robotics for pick-and-place activities in manufacturing firms, where lean management tools and practices are being embraced. Utilizing a multiple case study analysis, the researchers conducted on-site visits to production facilities and analyzed 16 diverse projects, 11 coming from manufacturing companies and 5 projects provided by System Integrators, to gain heterogeneous and wide-spanning insights. The unit of analysis is the single robotic implementation, spanning across various sectors to extract patterns independently from the specific industry. These projects yielded a substantial volume of information, knowledge, and best practices related to the adoption of Robotics. Following a meticulous examination of the case studies, a process model was formulated to guide companies through decision-making, implementation, monitoring, and sustain stages in robotics introduction projects. This research disentangles the influence of lean management in ensuring the optimization of benefits derived from such projects. The process model seeks to offer practical guidance for companies approaching the complexities of robotics integration within manufacturing processes, successfully filling in the pre-existing research gap.

Keywords: Robotics, Industry 4.0, Lean implementation, Process model.

1 Introduction

The trends of internationalization and globalization cause an increased degree of competitiveness, wherein customers heavily base their decisions on international comparisons, giving rise to a substantial degree of unpredictability and uncertainty [1]. The adoption of new technologies, classified as Industry 4.0, is a major tool to establish a competitive advantage [2]. This industrial revolution spans across various sectors and involves advanced technologies like 3D Printing, Cloud Manufacturing, Internet of Things (IoT), Cyber-Physical Systems (CPS), Big Data, and Advanced Robotics [3]. Additionally, the need for a sustainable approach to the manufacturing industry, combined with the drive for enhanced efficiency, has led to the adoption of Lean Management practices [4]. This method is centered on minimizing waste, eliminating non-value-added activities within manufacturing processes, reducing inventory, enhancing quality, and ensuring the production of the correct product, at the right time, and in the right quantity [5].

However, technological advancements, albite needed in today's processes, present some challenges on the social level: job displacement due to automation [6]. Directing investments towards innovative technologies represents an efficient approach to significantly reduce the dependency on human labor [7]. This includes the incorporation of technologies such as Advanced Robotics, capable of performing tasks traditionally assigned to manual workers.

Hence, it is crucial to differentiate between two distinct scenarios: the automation scenario, which is the worrisome one, and the human-centric scenario, which is far more beneficial. In the former, there is a prevalent Tayloristic approach to organizational structure, where tasks are broken down into tiny steps, leading to a significant reduction of the worker autonomy [8, 9]. Here, work is dictated by technology. In contrast, the latter scenario, which embodies the most appropriate approach to automation, places an emphasis on re-skilling and up-skilling workers, shaping the image of an Operator 4.0 who is smart and skillful, capable of collaborating effectively with robots and machines [10]. Though this optimistic vision embraces high flexibility, minimal task division, and fosters an open work environment, it still lacks a concrete implementation plan.

This article dives into this issue by delineating the successful implementation of Robotics in manufacturing companies utilizing the support of Lean Management practices.

2 Literature Review

Increased standardization, a characteristic inherent to Lean practices, was identified as one of the factors that positively influence the adoption of Robots, therefore it can be stated that the successful adoption of Robotics is more likely to occur in the context of a Lean factory [11]. The core principle of Lean Robotics is to maximize utility for the client while minimizing waste [12]. There is a noticeable rise in the adoption of Lean Robotics, a concept primarily designed to streamline processes and eliminate inefficient activities to [13]. The link between different types of wastes and the introduction of Human-Robot Collaboration has been highlighted [11]. Specifically, the reduction of MURI (people overburdening) with the improvement of Ergonomics and Safety and the reduction of MURA (unevenness) and MUDA (wastefulness) is linked with the enhancement of Efficiency. Additionally, it emphasizes the link between the Lean objective of defects elimination with improved efficiency due to Human-Robot Collaboration.

The implementation of autonomous mobile Robots is crucial in Smart Production as they serve to connect the entire factory, ensuring a seamless and consistent flow of operations [14]. In the study conducted by [15], advanced Robotics has had a significant impact on 10 out of the 14 Lean tools considered, including 3M, Jidoka, Just in Time, Kaizen, Kanban, Line-balancing, Poka-Yoke, Single Minute Exchange of Die SMED, Total Productive Maintenance TPM, and Work Standardization.

However, as [16] underlines, if a company opts for a traditional automation strategy, acquiring and integrating Industrial Robots without a carefully devised plan, it becomes challenging to align with Just-in-Time production, small batch sizes, and continuous improvement. To maintain a competitive advantage, users of Robots must ensure the elimination of "black boxes" from their factory floor, emphasizing the need for transparency and adaptability in the automation process.
However, a noticeable research gap has been identified as few frameworks regarding robotics management have been identified:

- A first example of the implementation model is restricted to manufacturing systems where, due to high costs of possible reorganization, Cobots are implemented in the AS IS context without a significant redesign. This model has the potential for further enhancement by including Industrial Robots and through the integration of specific Lean tools and analyses to be systematically applied at each stage of the framework. This extension could involve addressing distinct issues such as safety or ergonomics, which vary significantly between the two solutions [17].
- Other researchers shaped a framework for only the mitigation of Cobot Implementation Risks, linking specific Lean tools with potential challenges that may arise during Cobot implementation [18].
- Another example includes a Robotic implementation model in the construction industry. It highlights long-term benefits coming from enhanced productivity, quality, communication, innovation, safety, and many others. The framework shows recommendations and guidelines for three different facets: Technology, People and Organization [19]. Despite the limit to the construction sector, some of the underlined insights and analysis could be further extended to a broader context.
- Also, a framework to implement Robot Process Automation RPA is introduced with three stages (Initialization, Implementation and Scaling) and distinguishes between the actions to be done during the RPA project and the ones performed as continuous cycle. One area that could benefit from further exploration is the human dimension, particularly in terms of how to recognize and effectively tackle resistance to change and skill gaps [20]. This aspect represents a substantial potential risk that could impede companies from benefiting of the full benefits of Robotic implementation.

It has been noticed an absence of an all-encompassing and exhaustive process model, capable of providing comprehensive guidance to companies in implementation of robotics into their operational processes. Moreover, the influence of lean management along the different phases of the model has been identified as a crucial aspect to be analyzed empirically. The research questions have been devised as follows:

RQ 1: What is the process that manufacturing companies should follow to efficiently and effectively implement pick-and-place robotics?
RQ 2: How does lean manufacturing implementation in firms influence the implementation of robotics for pick-and-place activities?

3 Methodology

The need for empirical analysis to formulate an implementation process model for pick-and-place robotics necessitates exploratory case studies, with the unit of analysis the single robotic implementation within the manufacturing company. The focus of pick-and-place robotics implementation has been led by the contextual diffusion of implementation projects known by the authors at the moment of the research. This methodology is particularly relevant to develop and extend theory [21, 22]. Moreover, it supports the usage of several variables for a new phenomenon [23].
The research adopts the theoretical sampling approach and replication logic proposed by [24], with each company as an analytic unit and involved in robotics implementation. Utilizing a multiple case study analysis, the researchers conducted on-site visits to production facilities and analyzed 16 diverse robotics implementation projects, 11 coming from manufacturing companies (A to I) and 5 projects provided by System Integrators (J to N), to gain heterogeneous and wide-spanning insights. The valuable insights were gathered through multiple interviews and on-site visits. A structured document was created which summarizes all the key aspects to focus on during the interviews. The interviewees included Operations Managers, Heads of Production, and Senior Mechanical engineers who were managing the projects and were directly involved in the implementation of Robots. The interviews focused on the following dimensions:

- Chronological and logical sequence of steps associated with the project;
- Foundations, drivers, and reasons behind each decision;
- Correlation of each choice with previous and subsequent decisions;
- Integration and use of aspects related to Lean Management.

The analyzed companies are:

Table 1. Companies' profiles

Company	Sector	Size	Age or Number of years in operation	Period of lean adoption	Technologies adopted before automation	Data sources (e.g. interviews, corporate reports, etc.)
A	Industrial, Energy, Healthcare					

B	Semiconductor					
C	Automotive					
D	Retail					
E	Semiconductor					
F	Chemical					
G	Beverage					
H	Personal Care Products					
I	Food					
J	Automation					
K	IT and Consulting					
L	Packaging Machinery					
M	Industrial Automation					
N	Automation and Simulation					

4 Results and Discussion

After conducting a systematic analysis of all the case studies, the goal was to identify the recurring pattern that drives companies along the robotization process. Valuable insights were shared by both companies and System Integrators, offering comprehensive guidance on the necessary steps, from the initial conceptualization of the project to the final stages of the implementation process, to the monitoring and sustain phases. Below, the process model has been visually represented in Figure 1 Process Model.

The process model is divided into two primary phases. The initial phase encompasses all the decisions regarding the robotic project that the company, along with the System Integrator should undertake, including the assessment of objectives, identification of barriers, analysis of the current process (AS IS), rectification of inefficiencies, economic evaluation, and the tuning of all the details, leading to a final assessment stage. The subsequent phase of the process model is dedicated to the actual integration of the solution in the company plant, while effectively implementing all the decisions made in the decisional process, conducting specific training cycles, monitoring the performance of the process, and underscoring the significance of standardization for future projects. The rest of this part explains all steps of the process model.

STEP 1: GOAL DEFINITION

Step 1 consists in the identification of the main goals regarding the introduction of robotics. All these objectives are distinctly identified within the existing literature [14, 25–27].

- Ergonomics and safety: Employees must repetitively lift heavy loads, execute torso rotations, and work in uncomfortable postures. Robotics can play a crucial role in addressing ergonomic concerns and improve safety.
- Process and product quality: Certain tasks may be performed incorrectly due to operator distractions, or defects can go unnoticed during visual quality check. This may lead to rework and reprocessing. A robot is programmed to perform the task precisely and perform an objective and accurate quality check.
- Cost reduction: Robots can maintain a higher and continuous operational pace compared to human workers with less breaks.
- Productivity increase and absenteeism reduction: Concerns about absenteeism have become increasingly prominent, and depending on robots rather than human labor can secure a higher level of productivity, ensuring the ability to meet customer's demand.

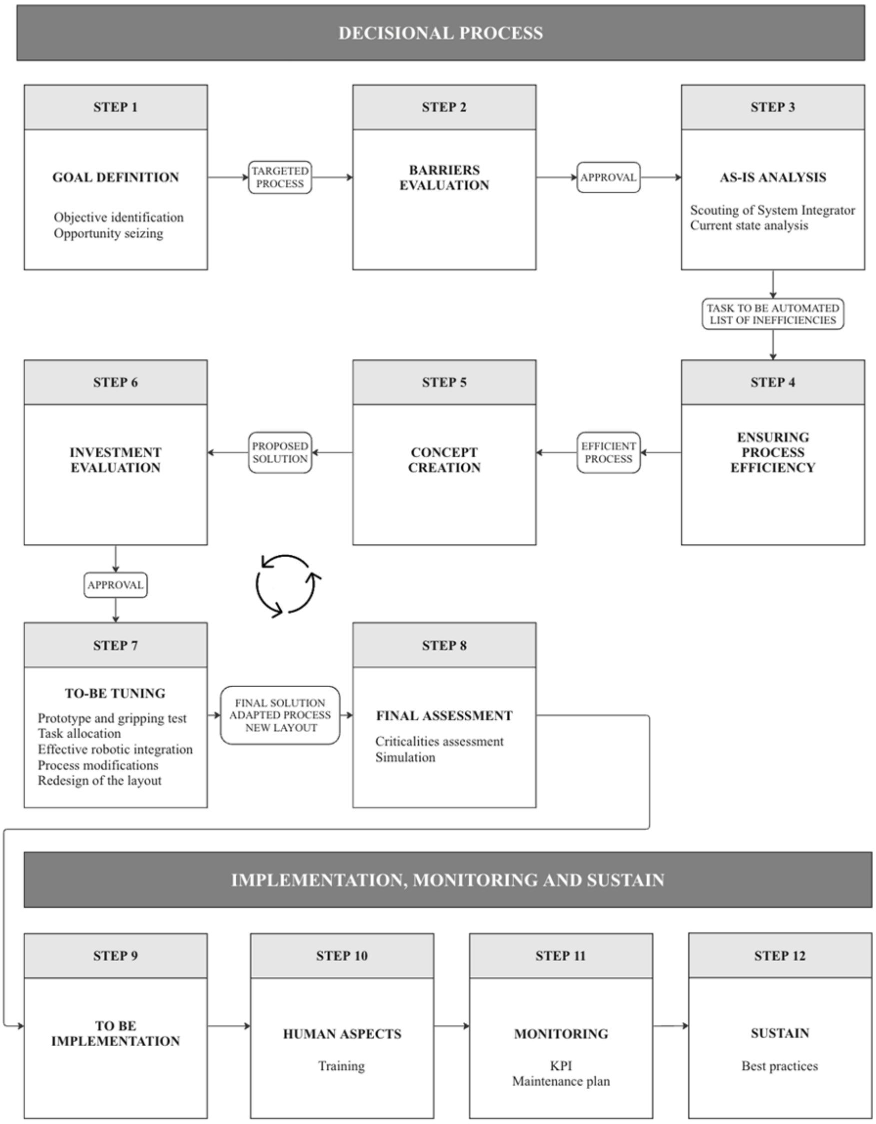

Fig. 1. Robotics Implementation Process Model

- Flexibility enhancement: In situations where pick-and-place activities were initially carried out by traditional mechanical machines, switching to a robotic solution can guarantee a higher degree of flexibility and adaptability [28]
- Standards and norms: Especially in the food sector, where stringent hygiene regulations and the absence of contaminants are legally required, pick-and-place activities are safer to be conducted by robotic arms rather than human workers.

Once the objectives and/or the opportunities to seize are clearly defined, the specific manufacturing process to focus on is the outcome of the first step.

STEP 2: BARRIERS EVALUATION

Step 2 consists in evaluating the barriers that can be traced back to those identified by [29]. However, due to the specific sector analyzed in the paper, not all the barriers identified by [29] were recognized within the case studies. The primary categories of barriers encountered in the research include process barriers, social barriers, economic barriers, and IT barriers. There is alignment with [28] as well, which underscores the critical issue of flexibility, as current Robot programming techniques may not be suitable for frequent changes in often highly customized products manufactured in small batches and additional barriers related to the need for additional skills in managing Robots. The most common barriers belong to process barriers, social barriers, economic barriers and IT barriers.

- Process barriers: while human operators can quickly adjust their grasp to accommodate various product shapes or dimensions, a robot lacks the same level of adaptability. For a robot even a slight variation in the product's tolerances can lead to the robot either failing to pick it or causing damage to the material, creating much more rigidity [29]
- Social barriers: The skill gap is one of the most crucial aspects in the Industry 4.0 era, especially in countries with low-skilled and cultured workforce needed to supervise robots and use Human Machine Interfaces. Consequently, this may be an obstacle to the acceptance and progression of these projects. Moreover, operators may exhibit resistance to innovation and to the adoption of a new work approach, stemming from their established habits of performing tasks [29].
- Economic barriers: Even though precise quotations have not been obtained, a preliminary macro-level investment analysis should be conducted in order to be aware of the budget constraints and make sure that the potential investment aligns with the financial availability of the company [29].
- IT barriers: Mapping all the possible configurations of pick-and-place activities may change according to the type of product handled, through software programming. The outcome of the second phase is the approval to start the project upon barriers analysis: the project can officially proceed [29].

STEP 3: AS-IS ANALYSIS

Step 3 consists in assessing the current situation of the process where the manufacturing company and the System Integrator conduct a detailed feasibility analysis:

- Scouting of System Integrator or Robotic supplier based on the reputation and positioning in the market, the quality of support provided throughout the project execution, and the assessment of previous collaborations or projects.
- Layout assessment and process mapping through mapping the physical space using visual maps, which easily allow to discern the placement of each resource within the layout, and identify any potential space unavailability or critical aspect.

- Performance and Risk Analysis that includes the bottleneck analysis, the comparison between takt time and cycle time, and Risk Analysis, that can be further integrated with a Process Failure Mode and Effects Analysis PFMEA.
- Inefficiencies identification and Root cause analysis: Following Lean management principles, Spaghetti Chart is a valuable tool to identify the sources of waste associated with transportation and movements. This precedes a Root cause analysis, that can be pursued with the help of tools such as Ishikawa diagram, or 5 Whys, to properly identify causes to eliminate them.

After a comprehensive analysis of the AS IS situation, it is possible to clearly identify the task to be automated and detail all the inefficiencies identified through the comprehensive set of analyses conducted on the process [12, 30].

STEP 4: ENSURING PROCESS EFFICIENCY

Step 4 consists in ensuring process efficiency through a constant pace of pick-and-place tasks by guaranteeing a smooth, constant, and continuous flow of the products or the minimization of the scrap rate. This necessitates the allocation of proper work content in terms of the number of movements a robotic arm should be able to conduct.

To rectify all the inefficiencies identified in Step 3, a variety of tools derived from Lean approach are commonly employed, among which TPM, SMED, Statistical Process Control SPC, Jidoka, Standardization of activities and Line balancing [12, 31].

At the conclusion of this phase, an efficient process is ensured. Consequently, the situation is optimal for accommodating the new robotic solution.

STEP 5: CONCEPT CREATION

Step 5 consists in the System Integrator exploring the most appropriate robotic solution that aligns with the process's requirements, often a Robot or a Cobot. The primary factors influencing the selection include working speed, weightlifting capacity, flexibility and movements requirements, space occupied by the solution and compatibility with the existing layout, extent of collaboration with human workers and safety requirements. The most common typologies of Robots for this kind of operations are Scara robots, Cartesian robots, Delta robots, Palletizing robots or Anthropomorphic robots. while taking into account the requisite number of axes for the robot. Together with the solution, specific safety measures must be devised, including the need for dedicated safety cells, protections, or sensors to prevent any collision or damage to the operator. Furthermore, it is crucial to design an intuitive interface, teach pendant, or Human Machine Interface HMI for the operators who need to interact with the Robot or Cobot. Ultimately, the determination of the number of robots to be installed can be based on the capacity requirements and the desired production pace to be maintained [32].

STEP 6: INVESTMENT EVALUATION

Step 6 consists in evaluating the investment through Key indicators like Payback time and Return on Investment. The company should assess various costs during the economic evaluation, among which the technological investment amount, depreciation, training costs, costs to implement safety measures, costs for re-layout, personnel costs, management costs, maintenance costs, running costs and the quantification of the expected benefits.

Upon completion and validation of the investment evaluation, the System Integrator receives approval for the initial quotation, and the technical study of the solution can actually start.

STEP 7: TO-BE TUNING

Step 7 involves the actual tuning of the details necessary for the introduction of robotics, with the support of the experience of the System Integrator [33, 34]:

- Prototype creation and gripping test: Once a prototype is created with the right software programming, a gripping test is conducted using real products to validate the functionality of the end-of-arm tooling and the accurate execution of the arm's movements. Based on the outcome of the test, specific modifications can be implemented to the end-of-arm tooling to ensure it fits well with the dimensions and material of the final product.
- Task allocation: Tasks that are physically demanding are typically delegated to the Robot/Cobot, while operators are generally assigned responsibilities related to support or supervision. In this phase the Lean principles of Employee Involvement in the redesign of the activities and standardization of the operational activities have been identified as the most common.
- Effective robotic integration: This phase is applied directly during the integration of the solution within the process. Five Lean initiatives can be implemented as part of the preparation for the introduction of robotics: 5S, SMED, SPC, Jidoka and Poka Yoke.
- Process modifications: In addition to these Lean tools, there may be further modifications required to adapt the process for the introduction of robotics, such as the establishment of specific requirements and tolerances for products, the redesign of packages or ensuring proper positioning of objects arriving to the Robot.
- Redesign of the layout: The company must initially consider the physical constraints of the plant, the constraints associated with the chosen Robotic solution, and the optimization of efficiency concerning the flow of products throughout the process. Additionally, safety considerations may imply the incorporation of barriers and robotic cells. Following Lean principles aligns seamlessly with the objective of addressing identified wastes, particularly concerning transportation and movement. The new layout should aim to minimize walking distances, eliminate obstacles from the operators' path, ensure appropriate working heights and surfaces, and uphold safety and ergonomic standards.

STEP 8: FINAL ASSESSMENT

Step 8 consists in a final assessment to determine that all the potential criticalities have been comprehensively addressed, through a Criticality assessment followed by a Simulation cycle [35, 36]:

- Criticalities Assessment: A comprehensive Risk analysis must be carried out. It's crucial to identify and mitigate any possible safety issue, inserting additional protections, sensors or other safety measures if needed. Also assessing specific ergonomic indicators, such as Ocra or Nisoh, to ensure compliance with standards and the well-being of operators. In this phase, a comprehensive PFMEA should be executed to proactively identify, classify and address potential risk before the effective implementation.
- Simulation: Various software solutions are available to test whether the product flow and action sequences have been precisely designed and to assess additional factors, including the robot capacity, productivity, and the assessment of specific KPIs.

This step represents the conclusion of the decision-making process, providing the ultimate assessment before initiating the final implementation of the solution. Steps 4, 5, 6, 7, and 8 may require an iterative approach, ensuring that the final solution is reached through a refined and repeated evaluation process.

IMPLEMENTATION, MONITORING AND SUSTAINING

STEP 9: TO BE IMPLEMENTATION

Step 9 entails the introduction of the selected robotic solution and the effective execution of pre-determined redesign decisions. During this stage, rigorous testing of the process incorporating the new robotic solution must be conducted, with a focus on identifying and resolving any anomalies that may arise, such as difficulties in the integration with other technological tools or the need to adjust the orientation of the products.

STEP 10: TRAINING

Step 10 requires a well-structured training program, coupled with continuous supervision and updates on its progress, ensures that operators remain adequately equipped with the right knowledge to oversee the robot's operations. The core competencies expected from operators include the ability in interfacing with the teach pendant, the capability to identify anomalies and know-how regarding basic preventive and corrective maintenance procedures. Additionally, the strict adherence to safety regulations while the robot is processing is fundamental, with an awareness of potential risks [37, 38].

Addressing human aspects to cultivate the right attitude toward change ensures active involvement of operators throughout the project and fosters a culture that highlights the benefits arising from the adoption of Robotics.

STEP 11: MONITORING

Step 11 consists in defining a package of performance monitoring indicators and devising a complete maintenance management plan for the robot:

- Performance monitoring indicator: Directly linked with the objectives of the project, specific indicators can be monitored along time, such as productivity, Ergonomic indicators, cumulative production, percentage of wrong positioned products or percentage of damaged products.
- Robotic maintenance management: Formulating a comprehensive maintenance plan should encompass both corrective and preventive maintenance. Additionally, in some cases the company schedules detailed preventive maintenance conducted by the supplier itself. The incorporation of a Lean Management approach, particularly Total Productive Maintenance, could prove beneficial. As for the entire line, this approach should be extended to Robot or Cobot.

STEP 12: SUSTAIN

The final step establishes a standardized approach, discerning the optimal practices that contributed to the project's successes. Conversely, when dealing with criticalities, it becomes fundamental to delve into the root causes of the issues, taking preventative measures to avoid their recurrence in subsequent projects. This step aligns with the Lean principle of Kaizen, which promotes continuous improvement. The focus is on fostering an environment where lessons learnt from both achievements and mistakes contribute to an ongoing enhancement of the way robotics projects are managed. The process is not linear, in fact, there is a learning process where companies enter into loop of feedback and learning and consequentially, adaptation. This is shown in the loop sign in figure 1.

5 Conclusion

To summarize, observing the process model generally holds validity for all the sixteen analyzed case studies, as all the steps were present in almost all the case studies. The only stages overlooked in certain projects pertain to the verification of efficiency preceding the introduction of the robotic solution and the execution of a software simulation prior to proceeding with the actual implementation. Companies that omitted these steps encountered challenges during the implementation phase, underscoring the strong importance of these preparatory phases before implementing Robotics. Therefore, despite heterogeneity in aspects such as the goals of robotic introduction and the industries in which companies operate, the process model developed has a strong empirical validity in representing the flow of steps guiding companies in.

To reinforce the research, more empirical evidence should be included, in particular referring to more quantitative data that could highlight what are the benefits of the process model and of including Lean in the implementation of robotics within manufacturing companies.

Lean management played a pivotal role in the process model, contributing to maximizing the benefits derived from the introduction of Robotics. Due to high costs of possible reorganization, Cobots are implemented in the AS-IS context without a significant need for redesign. This model introduced by [17] presents several differences. The initial point of difference from the presented model arises due to the intentional exclusion of this assumption in the research study presented. This exclusion is due to the overarching objective of the which aims to systematically tackle all the challenges associated with process adaptation and redesign. Another point of distinction with [17] lies in the model's exclusive focus on Cobots, neglecting the analysis of Industrial Robots. Differently, the underlying process model encompassed noteworthy considerations regarding the safety and speed of operation associated with Industrial Robots. This inclusion broadens the scope of the underlying study, allowing for a comprehensive understanding of diverse Robotic systems and their implications. The only assumption imposed within this research pertains to robotized pick-and-place activities within the manufacturing context, enabling a focused exploration of this crucial task within the industrial sector while maintaining the study's overall comprehensiveness. However, despite the differences, the steps of the model purposed by [17] were verified by the devised process model.

As for [19], several best practices inserted in the model align with those encountered in the conducted case studies, such as the need to provide training and hands-on experience for all individuals involved, and the necessity to standardize processes to optimize the utilization of Robotics. Nevertheless, the ultimate objective of the two models is inherently different. While the model of [19] categorizes best practices in the three areas, the aim of the research was to formulate a sequential series of actions to implement Robotics.

The reason why the process model can consistently generalize the steps of diverse projects lies in the assumption that all of them automate pick-and-place activities, which is characterized by a significant degree of standardization. The overall knowledge included within the process model is validated by the extant literature and confirmed by the empirical evidence gained through the case studies.

Furthermore, the study placed significant emphasis on the adoption of Lean Management practices. The incorporation of Lean Management proved advantageous for three primary objectives. Firstly, it played a fundamental role in analysing the current state of the process, bringing to light any potential inefficiencies. Secondly, many of the valuable tools of Lean Management were essential in addressing the identified inefficiencies, guaranteeing a streamlined process that ensures a continuous flow of products and waste minimization. This step is crucial since introducing Robotics into an inefficient process could aggravate its inefficiencies, preventing the company from the potential benefits coming from robotic integration. Lastly, the application of Lean Management tools in the context of Robotics introduction is essential for ensuring the optimal level of integration within the process.

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