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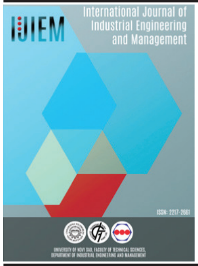

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Original research article

Maximizing efficiency and collaboration: Comparing Robots and Cobots in the Automotive Industry – A Multi-Criteria Evaluation Approach

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ABSTRACT

The fifth industrial revolution emphasizes human-robot collaboration to enhance transformation processes. While collaborative robots (cobots) are increasingly attracting interest in various industries, integrating them into assembly lines remains challenging. This paper aims to investigate whether cobots are replacing traditional robots or if a synergy between both technologies is essential in the era of Industry 5.0 to maximize benefits. The real case study presented provides a comparison between robots and cobots in an automotive factory using the Fuzzy AHP methodology. The results indicate that cobots are advantageous in production units with low-volume and high-variability tasks. However, they fall short of the reliability, precision, and productivity that traditional robots offer for repetitive tasks. Finally, a framework is proposed to guide decision makers in adopting the suitable solution to their needs while ensuring optimal performance as well as workers wellbeing.

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1. Introduction

The fifth industrial revolution is reintroducing a human centric approach to manufacturing with a focus on adaptive, and flexible production systems. The emergence of this new era is fostering greater collaboration between workers and intelligent machines [1]. The modern industrial market requires stronger resilience in meeting customer demands for personalized products, therefore transitioning from conventional programmable robots, which carry out repetitive tasks toward collaborative robots is aimed at assisting operators and enabling machines to coexist in the production space without any safety fence or barrier [2], [3]. Unlike traditional robots, collabor-

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ative robots are designed with sensors, force limiting and rounder geometric characteristics and conceived to work alongside humans [4].

Since the first industrial revolution, robots have undoubtedly been contributing to the improvement of quality and production systems, particularly in the automotive industry that has remained one of the primary customers of robots, with 119405 new robots installed in 2021 and a Compound Annual Growth Rate (CAGR) of 42% [5]. Cobots gained popularity with the emergence of the fifth industrial revolution and the interest in combination of human factors with the technological advances of the fourth industrial era [6], [7]. The global robotics technology market is forecasted to grow to $155 billion in 2027 at a CAGR of 14.9% where the global cobots market will represent only USD 9342.8 Million but an important CAGR of 38.5% [8], [9]. Therefore, there are high expectations that the adoption and implementation of cobots yield similar outcomes of traditional robots and extend the automation to a new horizon due to their appealing characteristics such as cost, flexibility, and small dimensions [10], [11].

These advances in robotics have attracted the interest of researchers. Several theoretical and comparative studies were elaborated to highlight the feasibility and benefits of integrating cobots in the manufacturing process. For instance, Y. Cohen et al. explored the key factors of cobot deployment considering the economic cost-benefit trade-off as well as the expected sociological and psychological effects, but this study was based only on literature review without any application in practice. In contrast, Salunkhe et al. have confirmed the feasibility of using a cobot for wheel hub nut assembly in a lab environment [12], however the comparative study was done between a human worker and cobot, without considering the fenced robot option and without the implementation in a real assembly line. Furthermore, Jesuthasan and Boudreau [13] proposed a 4 steps approach to help leaders in optimizing human-machine work combinations, this framework is categorizing the automation in three options: Robotic process automation, cognitive automation and social robotics but it doesn't consider the level of collaboration and other specific criteria of the factory. Thus, it is still challenging for industrials to select from different types and options the adequate solution to their specific needs, = which leads to highlight below research questions:

- RQ1: As cobots are considered from the enabling technologies of Industry 5.0 [14], are they eliminating traditional robots?
- RQ2: If not, what are the key differences between traditional and collaborative robots in the Industry 5.0 era?
- RQ3: How can decision makers select the best technology to their needs in the industry 5.0 era?

In order to answer to these questions, this paper provides a comparison between robots and cobots based on a multi-criteria analysis and realized for a company in the automotive industry. This company is required to integrate a new operation of screw-driving in its assembly line. Figure 1 describes the steps followed in this study.

Thereby, after presenting the human-robot collaboration in section 2, and describing the project in section 3, the multi-criteria analysis is reported in section 4, then results are discussed in section 5. Finally, the conclusion is provided in section 6.

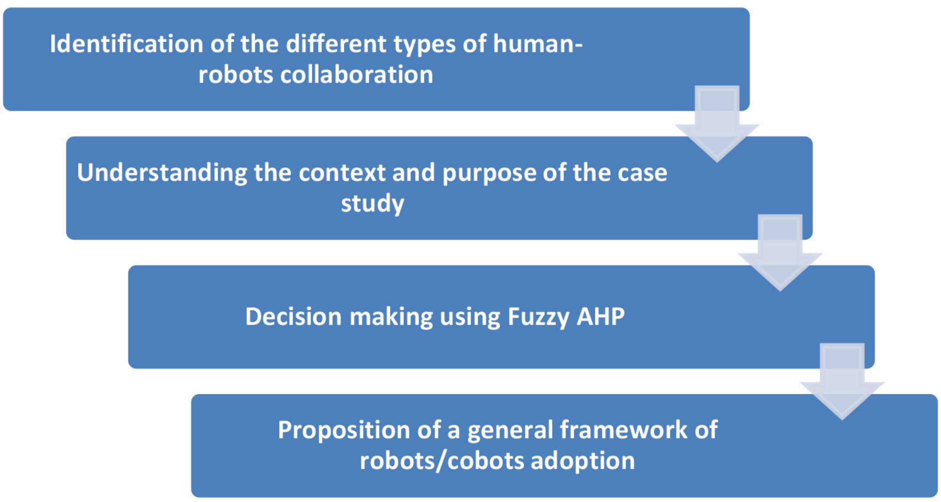

Figure 1. Research framework

2. Human-Robot collaboration

The term 'Cobot' was introduced by J. Edward Colgate and Michael Peshkin in 1999 to refer to collaborative robots in their paper "Cobots: Robots for Collaboration with Human Operators" in which they outlined the theoretical concept of cobots and their potential applications [15]. However, it was until 2008 when the first working prototype of cobots was presented by universal robots (UR5) [16], leading the interest of robots manufacturers to create customized versions on their own [17].

Cobots have been widely integrated across various applications in the automotive industry. In fact, this field is notorious for assembly lines designed for processing a set of different tasks with high demanding precision or entailing a risk of repetitive strain injury for human workers if performed manually [18]. Tasks such as packing, palletizing, welding, product assembly and material handling are among the areas where cobots are making significant contributions [19].

Depending on the type of required operations, cobots could be integrated in the production unit via 4 levels of collaboration [20]:

- **Coexistence**: The cobot and human worker operate in a shared workspace safely, without direct interaction or coordination.
- **Sequential collaboration**: The cobot and human worker take turns performing different parts of a task in a specific order.
- **Cooperation**: simultaneous action and interaction between the cobot and human worker throughout the entire task.
- **Responsive collaboration**: The cobot adjust its actions according to the human worker actions and instructions.

The international standards of safety requirements for industrial robots ISO 10,218–1/2 and ISO 15066, provide guidance on assessing risks and implementing appropriate safety measures to each level of collaboration. Thus, four safety modes are defined for cobots : Safety-rated monitored stop (SRMS) to ensure that the cobot will stop running when interacting with humans, Hand guiding (HG) for manipulating cobots by hand contact, Speed and separation monitoring (SSM) to control the speed of cobot based on the speed and distance of human worker, and Power and force limiting (PFL) that limits contact force or power to avoid any potential injury to human [21], [22]. Figure 2 illustrates collaboration levels with their corresponding safety modes.

The choice of the collaboration level depends on the specific task requirements, and the desired type of interaction and coordination between humans and robots. Thus, before starting the decision-making process, the existing assembly line as well as the new task requirements are discussed in the next section.

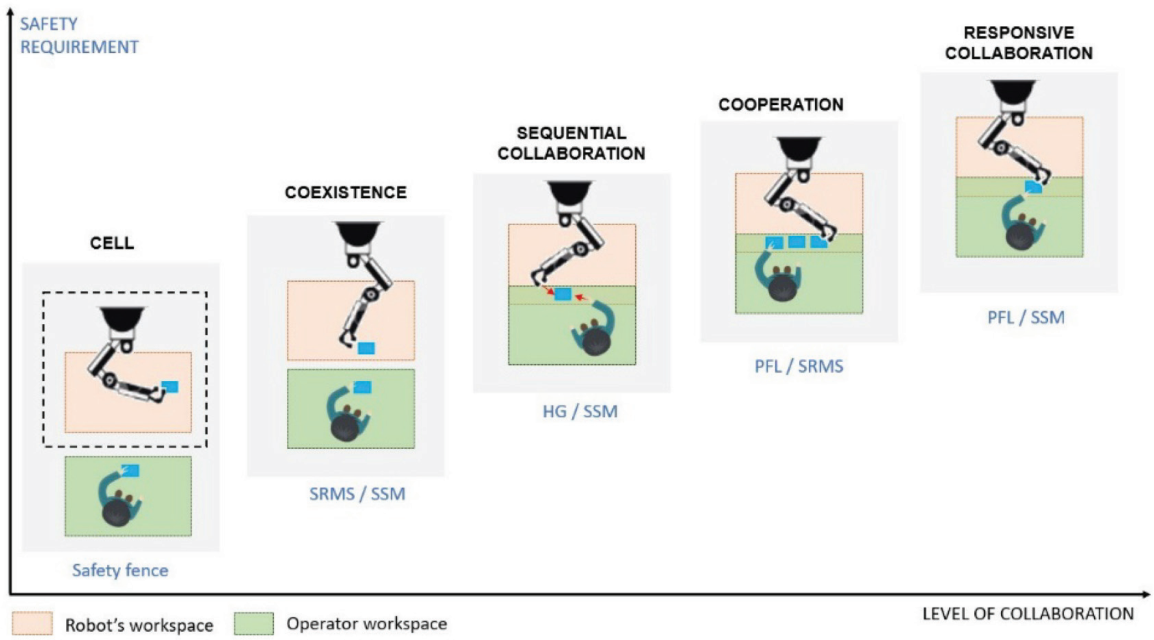

Figure 2. Collaboration levels of robots

3. Project description

3.1 Overview of the assembly line

This study is elaborated for a company specialized in wheels assembly and categorized tier 1, which is a direct provider to the Original Equipment Manufacturer. As illustrated in figure 3, the assembly line consists of four workstations, including three that are automated (Tire and rim assembly, inflation and bead-seat optimization) and one that is semi-automatic (Balancing).

- **Tire and Rim assembly**: The tire and rim are loaded onto two conveyors placed in a parallel layout. The size of each component is measured, and lubricant is applied to make mounting easier. The first robot moves the tire next to the rim, and then the second robot performs the assembly operation. The tire and rim assembly workstation is equipped with sensors that assist the two robots in completing the task, or in case of anomalies such as incorrect size, position or assembly, stop the process. Any necessary changes to the program are remotely implemented by the service provider.
- **Inflation**: At the inflation workstation, a bell is used to push the tire bead off the rim border (See figure 4). Then, the tire is inflated with air-blast under pressure until it reaches the desired pressure level. The tire is then returned to the rim boarder. The entire operation processes is carried out automatically and monitored by assembly line controls. Similar to the tire and rim assembly station, the inflation station is remotely supervised and fitted with a touch-panel to set the required pressure, as well as sensors that stop the process in case of anomaly.
- **Balancing**: At the balancing workstation, the wheel is automatically rotated to measure static and dynamic imbalances, and the results are displayed in a human-machine interface. A gripper, then, lifts the wheel and places it in front of the operator, who follows machine's instructions to correct the imbalance by adding weights. The workstation is equipped with a pick-to-light system to help the operator select the correct balancing weight, a laser projection system to show where to fix it, and a poka-yoke system to ensure the required quality. It is also fitted with sensors and remotely supervised.

This assembly line is characterized by modularity and a significant fast and automated changeover between multiple references. Moreover, it employs a cyber-physical system that facilitates the collaboration between workstations and enables mass customization while maintaining high quality standards.

3.2 Purpose of the study

The customer required to assemble a new type of wheels characterized by a new added component: Inserts, that are small covers fitted on the rim using screws. The company can't ensure inserts screwing with the existing equipment, so the integration of additional workstation(s) in the assembly line without impacting its global performance is mandatory. As presented in figure 5, this operation should be realized after bead seat optimization to avoid inserts damage in previous stations and before balancing to ensure accurate results.

According to previous studies, both robots and cobots provide better productivity than human operators in the manufacturing process [12], [21], [24], [25], but due to the lack of frameworks or case studies selecting between robots and cobots, the best solution for this project will be defined using the multi-criteria analysis described in the next section.

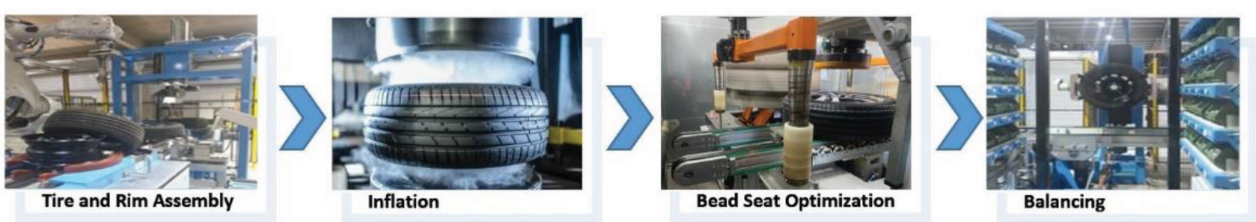

Figure 3. Workstations of the assembly line

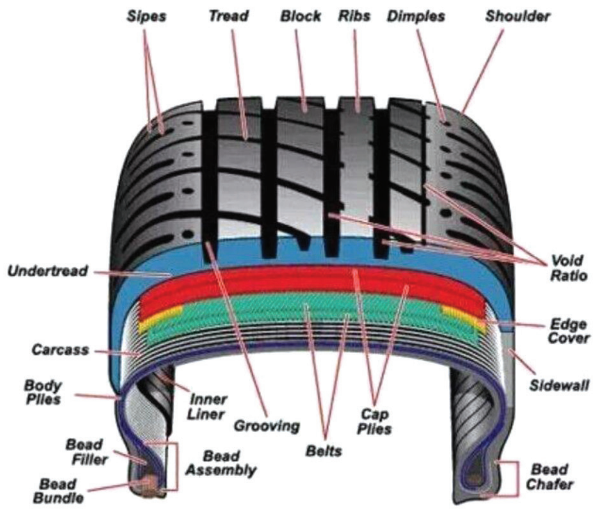

Figure 4. Tire terminology [23]

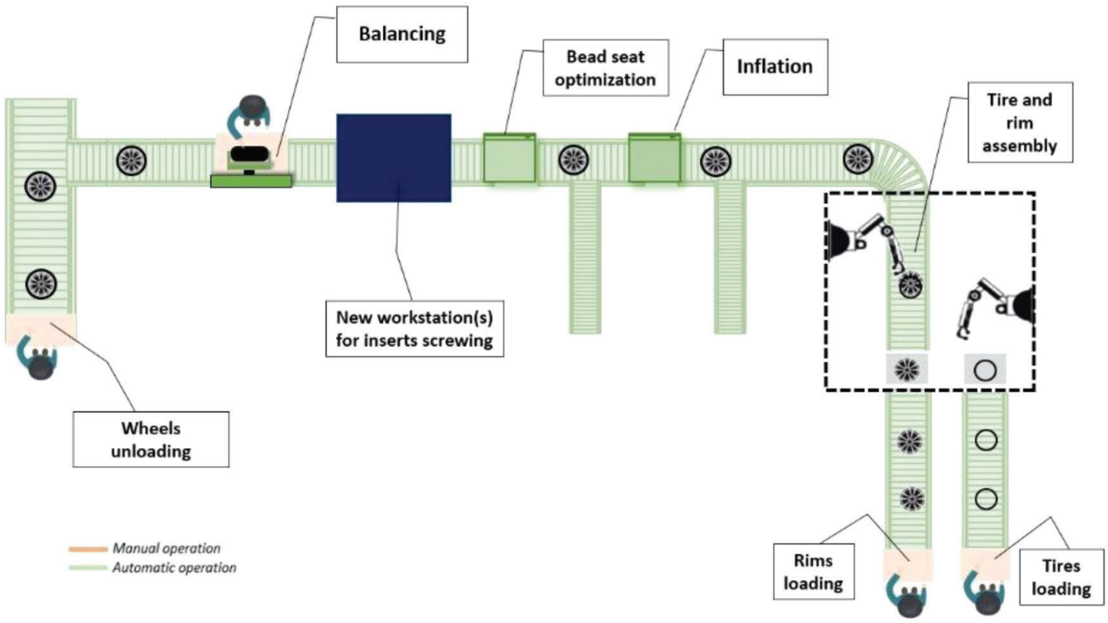

Figure 5. Integration of new workstation(s) in the assembly line

4. Decision making using Fuzzy AHP

4.1 Methodology

In many real-world situations, decisions involve multiple, often conflicting, criteria that need to be weighed against each other. The Multi-Criteria Decision Making (MCDM) is one of the most accurate approaches of decision-making that aims to provide a systematic and structured way to handle such complex decision problems and helps decision-makers to evaluate and rank alternatives based on multiple criteria or objectives [26]. Several MCDM methods exist such as AHP (Analytic Hierarchy Process), TOPSIS (Technique of Order of Preference by Similarity to Ideal Solution), ELECTRE (Elimination and Choice Expressing Reality), DEA (Data Envelopment Analysis), and VIKOR (Multi-criteria Optimization and Compromise Solution) [27], [28], [29]. Table 1 provides the key characteristics of each method.

AHP was the most popular method and was extensively applied in different fields due to its ease of use as well as the ability of structuring problems systematically and calculating both criteria weights and alternative priorities which leads to make optimal decisions [28], [29], [31], [32]. However, AHP can't handle uncertainty or vagueness, thus its combination with fuzzy set theory makes the comparison process more flexible and provides more accurate decision-making [8], [28], [29], [31].

Table 1. Comparison of MCDM methods

MCDM Method	Description	Strengths	Limitations	References
AHP	Pairwise comparison of hierarchical criteria considering difference information.	1. Flexible, intuitive and checks inconsistencies 2. Since problem is constructed into a hierarchical structure, the importance of each element becomes clear. 3. No bias in decision making 4. Relatively easy calculation algorithm 5. Possibility of estimating both the weighting of decision factors and the possibility of constructing rankings of the variants under consideration 6. Possibility of integration with other methods	1. Uncertainty – not supported 2. Possible problems with maintaining the consistency of pairwise comparisons when more elements are taken into consideration	[26], [29], [30]
Fuzzy AHP	AHP with the fuzzy evaluation of the alternatives.	1. AHP strengths 2. Possibility of taking uncertain information into account	1. More time-consuming (as compared to AHP) 2. More complex algorithm (as compared to AHP) 3. Possible problems with maintaining the consistency of pairwise comparisons when more elements are taken into consideration	[26], [30]
TOPSIS	Evaluating based on the distance of alternative to the ideal solution.	1. Possibility of performing calculations in a regular spreadsheet 2. Is based on quantitative data 3. Identification of patterns and anti-patterns 4. Possibility of integration with other methods	Need to weigh decision factors using other methods	[26], [30]
ELECTRE	Outranking the relationship of the alternatives and using pairwise comparison	Outranking is used	Time consuming	[26], [29]
DEA	Performance assessment of a set of homogeneous DM units with multiple inputs and outputs.	1. Multiple inputs and outputs can be handled. 2. Relation between inputs and outputs are not necessary. 3. Comparisons are directly against peers 4. Inputs and outputs can have very different units	1. Measurement error can cause significant problems 2. Absolute efficiency cannot be measured. 3. Statistical tests are not applicable. 4. Large problems can be demanding.	[26], [29]
VIKOR	A compensatory version of TOPSIS that is based on minimizing the distance to the ideal solution using a linear normalization approach.	1. Possibility of performing calculations in a regular spreadsheet 2. Is based on quantitative data 3. Identification of patterns and anti-patterns 4. Possibility of integration with other methods 5. Possibility of defining a compromise solution	Need to weigh decision factors using other methods	[26], [30]

Fuzzy AHP was applied in different industries especially in the automotive sector [28]. It can be performed via Buckley's approach which is involving the use of geometric mean for weights calculation [33], or Chang's approach that relies on an extent analysis method [10]. The Buckley's approach is utilized in this case study because it ensures a single solution for matrix comparison, unlike Chang's approach that does not provide estimates of the true weights from a fuzzy comparison matrix and may lead to wrong decisions [32], [34] . Figure 6 describes the 8 steps of the decision-making process.

- **STEP 1. Alternatives and criteria identification:** Alternatives and criteria are selected by the project team that is defined based on the policy of the company, it contains the Plant director and representatives of Quality Safety and Environment, Process, Production and Maintenance departments.

- **STEP 2. Pair-wise comparison of criteria and alternatives:** The identified alternatives and criteria are evaluated by the process expert in a pair-wise comparison matrix according to Saaty scale provided in table 2 [35]. The obtained matrix is presented in equation 1, it has n lines and n columns, where n represents the number of criteria / alternatives.

$$A = [x_{ij}] = \begin{bmatrix} 1 & x_{12} & \cdots & x_{1n} \\ 1/x_{12} & 1 & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/x_{1n} & 1/x_{2n} & \cdots & 1 \end{bmatrix} \quad (1)$$

Table 2. Saaty scale

Intensity of importance	Reciprocal	Definition	Explanation
1	**1**	Equal importance	Both activities contribute equally to the objective
3	**1/3**	Moderate importance	Experience and judgement slightly favour one activity over another
5	**1/5**	Strong importance	Experience and judgement strongly favour one activity over another
7	**1/7**	Very strong importance	An activity is favoured very strongly over another, its dominance is demonstrated in practice
9	**1/9**	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	**1/2 , 1/4 , 1/6 , 1/8**	Intermediate values between the 2 adjacent judgments	When a compromise is needed

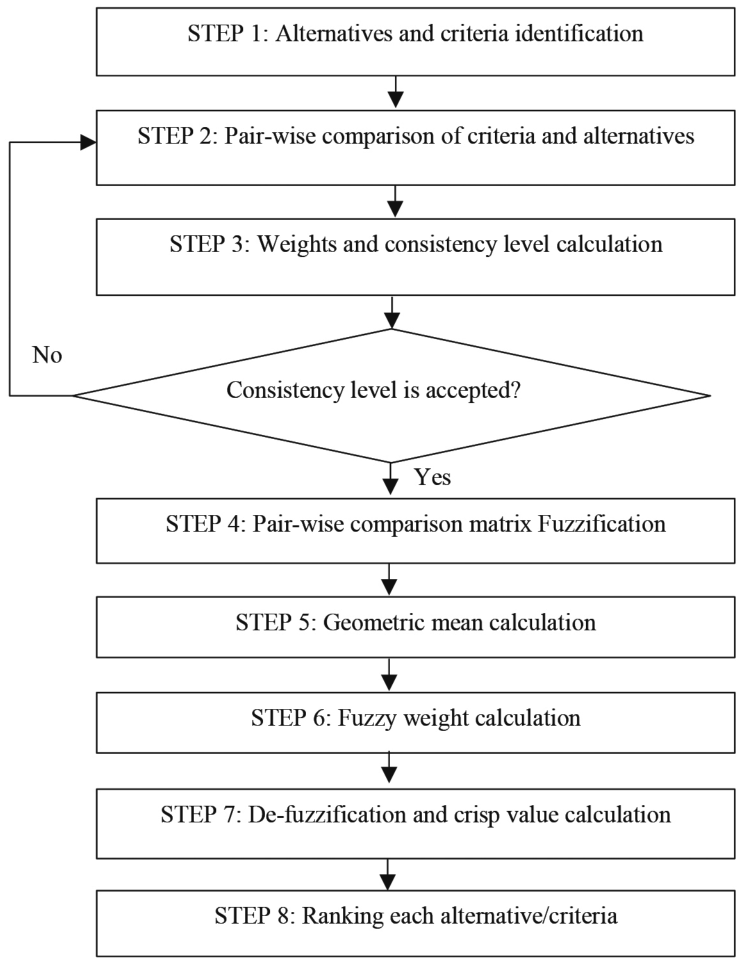

Figure 6. Flowchart of the decision making process

- **STEP 3. Weights and consistency level calculation:** The pair-wise comparison matrix is normalized via dividing every entry in the matrix by the sum of each column. The average of each row presents the relative weight. The consistency ratio is then calculated according to Equation (2) where λmax is the maximum eigenvalue , n is the size of the matrix, and RI is the random indice calculated according to table 3 [36]. Judgments that have a CR lower than 0.1 are reasonable [37] .

$$\mathrm{CR} = \frac{\lambda \max - \mathrm{n}}{\mathrm{RI}\,(\mathrm{n}-1)} \tag{2}$$

- **STEP 4. Pair-wise comparison matrix Fuzzification:** The Fuzzification is done by replacing the AHP scale by its corresponding Triangular fuzzy number according to table 4 [32], The triangular membership function is selected because it is well suited for representing uncertain or imprecise information and allows to express the preferences in a flexible and intuitive way [38], [39].

  The fuzzy pair-wise matrix is consequently presented in Equation (3):

- **STEP 5. Geometric mean calculation:** The fuzzy geometric mean is calculated for each row via Equation (4):

$$\tilde{r}_i = \left(\prod_{j=1}^{n} x_{ij}\right)^{1/n} \tag{4}$$

- **STEP 6. Fuzzy weight calculation:** it is realized according to the equation (5):

$$\widetilde{w}_i = \widetilde{r}_i \times (\widetilde{r}_{i=1} + \widetilde{r}_{i=2} + \cdots + \widetilde{r}_{i=n})^{-1} = = (l_{wi}, m_{wi}, u_{wi}) \tag{5}$$

- **STEP 7. De-fuzzification and crisp value calculation:** Fuzzy weights are transformed to crisp values according to the Centre of Area (COA) de-fuzzification method using equation (6). Then the normalized weight is calculated via equation (7).

$$G_i = \frac{l_{wi} + m_{wi} + u_{wi}}{3} \tag{6}$$

$$W_i = \frac{G_i}{\sum_{i=1}^{n} G_i} \tag{7}$$

$$\tilde{A} = [\tilde{x}_{ij}] = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (1/u_{12}, 1/m_{12}, 1/l_{12}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ (1/u_{1n}, 1/m_{1n}, 1/l_{1n}) & (1/u_{2n}, 1/m_{2n}, 1/l_{2n}) & \cdots & (1,1,1) \end{bmatrix} \tag{3}$$

Table 3. Random consistency index

n	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 4. Scale of AHP and Triangular Fuzzy Number

AHP scale	Linguistic variable	TFN scale	Inverse
1	Equally important	(1,1,1)	(1,1,1)
2	Intermediate 1	(1,2,3)	(1/3,1/2,1)
3	Moderate important	(2,3,4)	(1/4,1/3,1/2)
4	Intermediate 2	(3,4,5)	(1/5,1/4,1/3)
5	Important	(4,5,6)	(1/6,1/5,1/4)
6	Intermediate 3	(5,6,7)	(1/7,1/6,1/5)
7	Very important	(6,7,8)	(1/8,1/7,1/6)
8	Intermediate 4	(7,8,9)	(1/9,1/8,1/7)
9	Absolutely important	(8,9,9)	(1/9,1/9,1/8)

- **STEP 8. Ranking each alternative/criteria:** The normalized weights of an alternatives are multiplied by the weight of associated criteria. Then the sum of all multiplied values represents the score of the alternative. The priority is allocated to the alternative having the highest score.

4.2 Results

The decision making process related to the added operation of screwing in the assembly line is performed following the 8 steps described in previous section:

STEP 1: Alternatives and criteria identification

Alternatives identification.

The screwing operation can be realized via 2 options:

(1) **Manual assembly:** The operator will position components in the jig then assemble inserts manually using a screwdriver as presented in figure 7. This option requires an estimated cycle time of 130s and is not flexible as the jig should be changed according to each reference change.

(2) **Automatic assembly:** The operator will position inserts on rim and the robot will screw inserts. This option can be illustrated differently based on the collaboration level as shown in figure 8. The fenced robots can screw inserts after their positioning in an estimated cycle time of 45s. In the shared workplace, the cobot can do the same operation but without fences in a cycle time of 52s. In the sequential collaboration, insert positioning can be followed by screwing operation in the same workstation and in an estimated cycle time of 78s. The cooperation and responsive collaboration are not applicable for this operation due the repetitiveness and sequence of tasks.

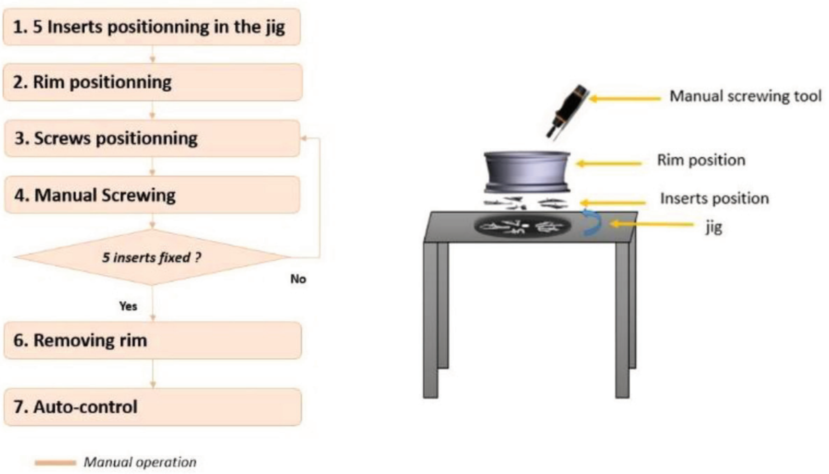

Figure 7. Manual assembly

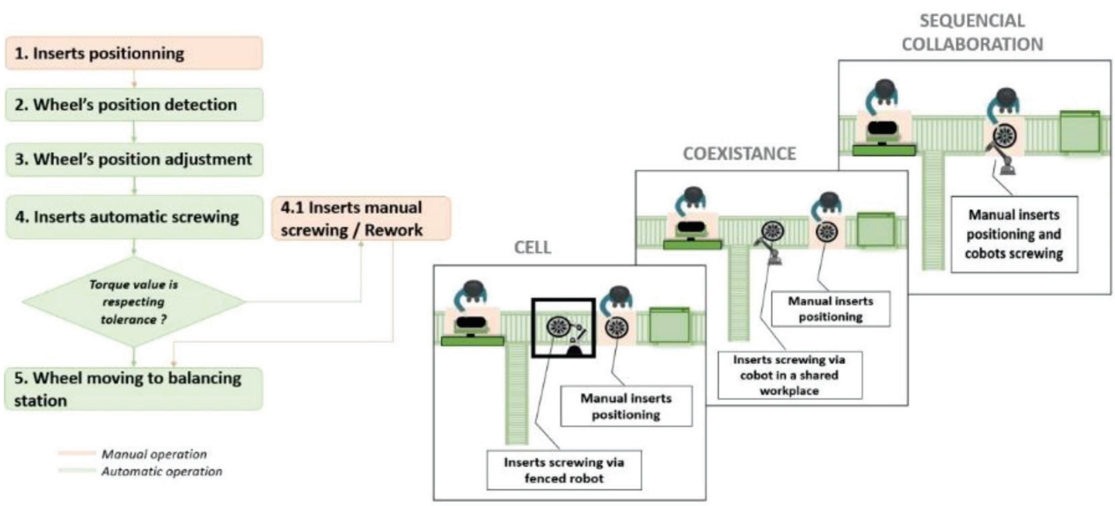

Figure 8. Automatic assembly

The cycle time of manual assembly is long and doesn't meet the required capacity. Thus, this option will be implemented in a pre-assembly workstation and adopted as back-up of the automatic assembly. The sequential collaboration presents also a long cycle time and will impact the global performance if integrated in the assembly line, so it is not considered in this study. The rest of the options, inserts assembly using a fenced robot or cobot after their manual positioning, will be compared in the next steps.

According to the technical data sheet of proposed robot and cobot available in supplier's website, their technical characteristics are summarized in Table 5.

They have both the same number of axes and payload (the maximum weight that a robot can lift and/or manipulate). The robot is heavier than the cobot but it allows better repeatability (the ability of a robot to return to a specific point in space accurately and consistently) and speed, additionally its working range (the maximum distance that its end-effector can travel along a specific direction or axis) is slightly bigger than cobot.

Criteria identification.

Based on the expertise of the multidisciplinary team and considering the company objectives, customer requirements and product and process characteristics, 8 criteria are defined for this case study:

- **Cost:** The cost of robots and cobots vary depending on their application and required capabilities. In addition to the initial cost, maintenance and operation costs must also be compared in the selection phase to ensure maximum benefits.
- **Reliability:** The reliability of a robot or cobot have an impact on safety and efficiency, it is assessed considering the quality and durability of their components, such as motors, sensors, and software.
- **Spare parts availability:** It is important to check the availability of spare parts before purchasing a Robot or Cobot, and to consider the lead time for spare parts reception as well as the supplier's support for maintenance if needed to make sure that any necessary repair could be realized efficiently with minimum downtime.
- **Programming:** The ease of programming, the available programming tools and languages, and the level of expertise required to program the robot or cobot are evaluated to check the flexibility and the ability to adapt to changing needs.
- **Precision:** The precision impact the quality of product and customer requirements. It depends on the quality of sensors, the stability of robot or cobot components, and the level of control and feedback in the programming. Robot and cobot precision is compared referring to their positioning accuracy and repeatability.
- **Interaction with humans:** Depending on the level of interaction with human required in the operation, mental workload and protective measures are evaluated to ensure operator's safety and wellbeing in the working area.
- **Productivity:** To assess productivity, the speed and accuracy of the robot and cobot movements are compared considering the automation level and integration with other equipment in the assembly line.
- **Space requirement:** The size and shape of the robot and cobot need to be compared, as well as any additional components, such as controllers or safety barriers in order to select a solution that is designed to fit within the available space.

Cost, programming, precision, productivity and space requirements were also identified by Silva et al. from literature review as criteria to be considered in cobots adoption decision process [40] where the availability and reliability were highlighted by Mecheri and Greene in their proposed methodology of cobots selection using AHP [41].

Table 5. Technical characteristics of proposed robot and cobot

Characteristic	Robot	Cobot
Number of axes	6	6
Max Working range	1440 m	1300 m
Max Payload	12 Kg	12 kg
Weight	150 kg	33,3 Kg
Repeatability	+/-0,02 mm	+/-0,1 mm
Max speed	260°/s - 700°/s	120°/s-180°/s

STEP 2: Pair-wise comparison matrix

The importance of each criteria and alternatives are evaluated by the process expert. Table 6 summarizes the criteria comparison, and table 7 provides an example of alternatives assessment according to the productivity criteria.

STEP 3. Weights and consistency level calculation

The weight is calculated for each comparison matrix. The consistency ratio obtained for criteria evaluation is 0.0007.

STEP 4. Pair-wise comparison matrix Fuzzification

After the validation of expert's judgement, the AHP score is converted to Fuzzy triangular number as presented in table 8 for the example of criteria.

STEP 5, 6 and 7 Geometric mean and weights calculation

The geometric mean and weights are calculated for all criteria and alternatives, Table 9 shows results of criteria.

STEP 8. Ranking each alternative/criteria

The score of robot and cobot is calculated in table 10 based on their weight and criteria weight. The robot present the highest score and consequently is the best solution for this project.

4.3 Integration of selected solution in the assembly line

After deciding that the traditional robot is the best solution for inserts screwing, the company ordered required equipment including the screwdriver, the workstation, and safety fences. The programming and simulations of screwing were realized by the service provider, then technical trails were elaborated by the project team after receiving parts and equipment installation (see figure9 and figure 10).

Results of simulation and technical trials matched the theoretical study. The screwing station was integrated in the assembly line without impacting its capacity. The real cycle time was improved to 40s. After 1 month of operating, there were no quality issues detected neither corrective maintenance or spare parts utilization.

Table 6. Pair-wise comparison matrix of criteria

	Cost	Reliability	Spare parts availability	Programming	Precision	Interaction with humans	Productivity	Space requirement	Average
Cost	1	0.333	0.333	1	0.2	3	5	7	1.644
Reliability	3	1	3	7	1	7	1	7	3.667
Spare parts availability	3	0.2	1	7	0.333	9	0.333	7	2.978
Programming	1	0.143	0.143	1	7	1	0.143	7	1.571
Precision	5	1	3	0.143	1	9	3	7	2.857
Interaction with humans	0.333	0.143	0.111	1	0.111	1	0.143	1	0.418
Productivity	0.2	1	3	7	0.333	7	1	7	3.222
Space requirement	0.143	0.143	0.143	0.143	0.143	1	0.143	1	0.285

Table 7. Pair-wise comparison of robot and cobot according to the productivity criteria

Productivity	Robot	Cobot
Robot	1	7
Cobot	0.143	1

Table 8. Fuzzy pair-wise comparison matrix of criteria

	Cost	Reliability	Spare parts availability	Programming	Precision	Interaction with humans	OEE	Space requirement
Cost	(1, 1, 1)	(0.250, 0.333, 0.500)	(0.250, 0.333, 0.500)	(1, 1, 1)	(0.167, 0.200, 0.250)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)
Reliability	(2, 3, 4)	(1, 1, 1)	(4, 5, 6)	(6, 7, 8)	(1, 1, 1)	(6, 7, 8)	(1, 1, 1)	(6, 7, 8)
Spare parts availability	(2, 3, 4)	(0.250, 0.333, 0.500)	(1, 1, 1)	(6, 7, 8)	(0.250, 0.333, 0.500)	(8, 9, 9)	(0.250, 0.333, 0.500)	(6, 7, 8)
Programming	(1, 1, 1)	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	(1, 1, 1)	(6, 7, 8)	(1, 1, 1)	(0.125, 0.143, 0.167)	(6, 7, 8)
Precision	(4, 5, 6)	(1, 1, 1)	(2, 3, 4)	(0.125, 0.143, 0.167)	(1, 1, 1)	(8, 9, 9)	(2, 3, 4)	(6, 7, 8)
Interaction with humans	(0.250, 0.333, 0.500)	(0.125, 0.143, 0.167)	(0.111, 0.111, 0.125)	(1, 1, 1)	(0.111, 0.111, 0.125)	(1, 1, 1)	(0.125, 0.143, 0.167)	(1, 1, 1)
Productivity	(0.167, 0.200, 0.250)	(1, 1, 1)	(2, 3, 4)	(6, 7, 8)	(0.250, 0.333, 0.500)	(6, 7, 8)	(1, 1, 1)	(6, 7, 8)
Space requirement	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	(0.125, 0.143, 0.167)	(1, 1, 1)	(0.125, 0.143, 0.167)	(1, 1, 1)

Table 9. Geometric mean and weights of criteria

	Geometric mean	Fuzzy weight	Crisp weight (COA)	Normalized weight
Cost	(0.701 ,0.855 ,1.060)	(0.069 ,0.098 ,0.143)	0.103	0.100
Reliability	(2034 ,2387 ,2.692)	(0.199 ,0.273 ,0.364)	0.279	0.269
Spare parts availability	(1060 ,1320 ,1.669)	(0.104 ,0.151 ,0.226)	0.160	0.155
Programming	(0.530 ,0.574 ,0.624)	(0.052 ,0.065 ,0.084)	0.067	0.065
Precision	(1486 ,1786 ,2.034)	(0.145 ,0.204 ,0.275)	0.208	0.201
Interaction with humans	(0.242 ,0.262 ,0.300)	(0.024 ,0.030 ,0.041)	0.031	0.030
Productivity	(1170 ,1385 ,1.641)	(0.114 ,0.158 ,0.222)	0.165	0.159
Space requirement	(0.168 ,0.189 ,0.215)	(0.016 ,0.022 ,0.029)	0.022	0.022

Table 10. Score of robot VS cobot

	Criteria Weight (Cr)	Robot Weight (Ro)	Cobot Weight (Co)	Score of Robot (Cr x Ro)	Score of Cobot (Cr x Co)
Cost	0.100	0.500	0.500	0.050	0.050
Reliability	0.269	0.743	0.257	0.200	0.069
Spare parts availability	0.155	0.743	0.257	0.115	0.040
Programming	0.065	0.200	0.800	0.011	0.054
Precision	0.201	0.900	0.100	0.181	0.020
Interaction with humans	0.030	0.100	0.900	0.003	0.027
Productivity	0.159	0.874	0.126	0.139	0.020
Space requirement	0.022	0.257	0.743	0.006	0.016
Sum				**0.704**	**0.296**

Figure 9. Screwing workstation

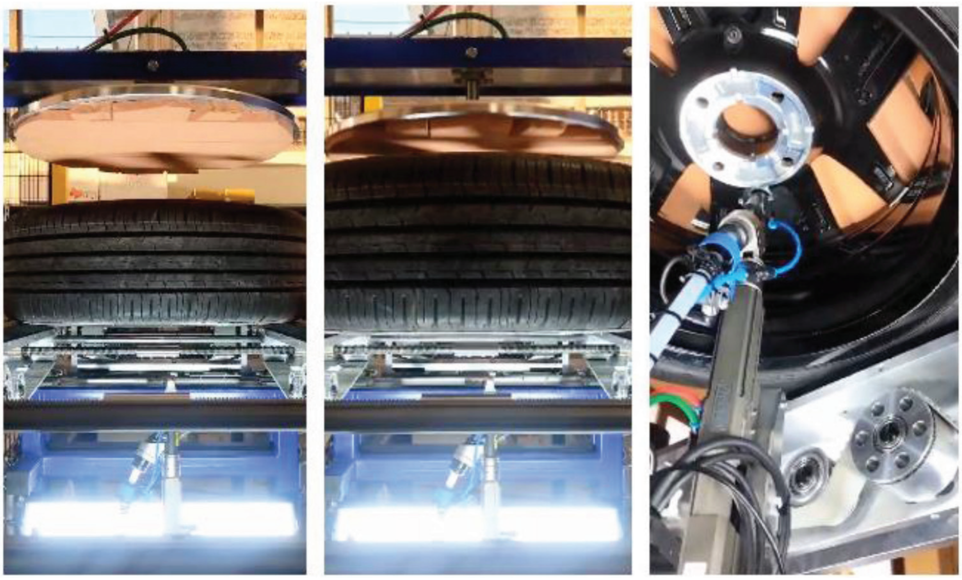

Figure 10. Screwing trials after equipment installation

5. Discussion

This case study provides a compelling insight into the continued relevance of traditional robots within Industry 5.0. Traditional robots remain unmatched when it comes to addressing repetitive tasks, offering unparalleled reliability, precision, and heightened productivity. By seamlessly taking over such tasks, they alleviate the burden on human workers and ensure consistent, error-free performance.

Conversely, the emergence of cobots presents a paradigm shift in industries where tasks necessitate flexibility and close interaction with human counterparts. Cobots, with their user-friendly programming and advanced safety features, are ideally suited for collaborative environments. Their ability to adapt to dynamic workflows and work alongside humans without compromising safety is a game-changer. Moreover, their compact design enables them to navigate tight spaces and overcome spatial limitations, a challenge often encountered by traditional robots. Table 11 summarizes the key differences between robots and cobots.

In the landscape of Industry 5.0, the synergy between traditional robots and cobots is evident. While traditional robots excel in repetitive, high-precision tasks, cobots fill the gap by facilitating human-robot collaboration and addressing ergonomic and spatial constraints. This dual approach not only maximizes efficiency and productivity but also ensures a safer and more agile work environment. Embracing the distinct advantages of both technologies is key to harnessing the full potential of Industry 5.0.

The comparison of robot and cobot characteristics according to the specific requirements of each project is crucial for manufacturers to make informed

Table 11. Traditional and collaborative robots adoption in the era of industry 5.0

	Traditional Robot	Collaborative robot
Human-Robot Collaboration	Robots perform repetitive and physically demanding tasks autonomously, reducing the need for human involvement in such activities	Cobots are designed to work alongside operators, and complement human capabilities rather than replacing them, promoting direct interaction and cooperation
Hyper personalization	Robots are suitable for mass production but they are not easily adapted to new processes or product variations	The agility and versality of cobots allow them to efficiently handle small-batch or customized production
Workers Well-being	By freeing workers from monotonous or physically demanding tasks, robots create opportunities for creativity and engagement in more intellectually stimulating work.	By collaborating with cobots, operators can focus on tasks that require decision-making, creativity, problem-solving, and complex dexterity.
Safety	Robots prioritize safety through physical barriers, keeping humans at a safe distance from the robot's workspace.	Cobots are equipped with advanced safety systems that enable them to detect human presence and avoid collisions or accidents.
Skills Requirements	Specific knowledge and programming skills are required to operate a robot	Cobots can be easily programmed and taught by operators using demonstrations or manual guidance

decisions about human-robot collaboration in their manufacturing processes. To aid in this decision-making process, a general framework is proposed in Figure 11, which provides guidance tailored to the unique needs of each project.

The integration of a new robot/cobot starts by identifying the task that needs to be automated as well as the specific requirements and constraints, such as the desired output, cycle time, and available space. Then, the adequate options of robot/cobot are selected and compared using the Fuzzy AHP method considering the key factors impacting the decision making. These factors include the nature of the task, such as its repetitiveness, complexity, and the degree of interaction required with human workers. Additionally, considerations related to safety, cost, performance, and required training are among the criteria of comparison. The robot/cobot that is ranked the highest is the most suitable for the task considering the overall scores. Finally, the selected solution is integrated in the manufacturing process, this includes tasks such as installation, programming, configuring interfaces, and ensuring compatibility with the existing equipment and systems. This approach ensures that the chosen technology aligns closely with the goals of the manufacturing process, optimizing efficiency, productivity, and safety in the era of Industry 5.0.

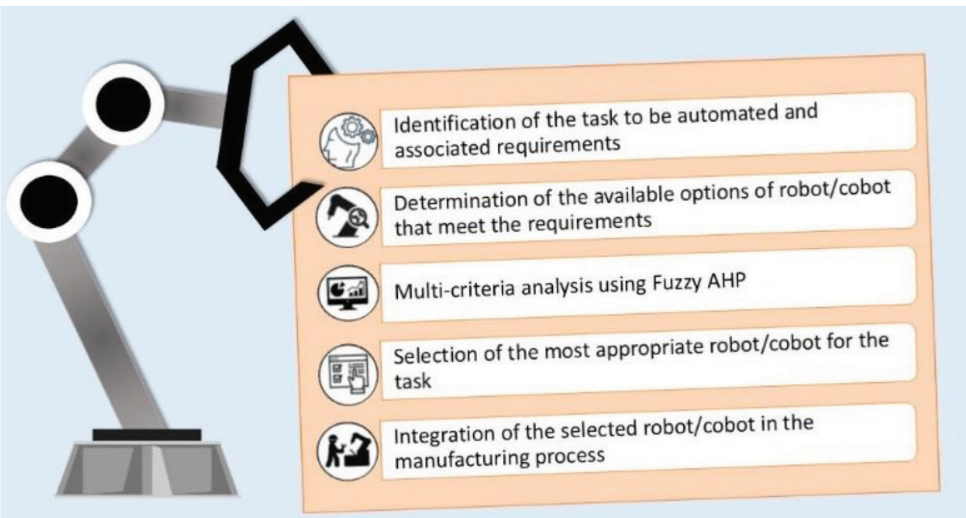

Figure 11. General framework of robot/cobot adoption in the manufacturing process

6. Conclusion

Even the fact that cobots are from the key enabling technologies of industry 5.0, they are not replacing traditional robots in all operations of manufacturing processes. The real case study of integrating the screwing operation in an assembly line of an automotive company, discussed in this paper, presents an example of the limitations of this new technology.

As traditional robots and cobots can provide different advantages in the era of industry 5.0, a general framework was proposed to help industrials select the level of human-robots collaboration that is adequate to their needs. This framework could be improved in future research based on additional studies in different processes and/or sectors and integrating more details on implementation.

The focus only on technical characteristics of robots/cobots in this case study as well as the single evaluation matrix are also among the limitations of this paper; future studies based on a panel of experts evaluation and considering additional factors related to human robots co-working will allow to have more accurate results in the decision making process.

Finally, the improvement of the performance of cobots in terms of reliability, precision and productivity is a challenge that should be addressed by robotics industrials to extend the use of this new technology in a wider range.

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