Scientific Paper / Artículo Científico

UNIVERSIDAD POLITÉCNICA SALESIANA ECUADOR
INGENIUS
Revista de Ciencia y Tecnología
https://doi.org/10.17163/ings.n36.2026.01
pISSN: 1390-650X / eISSN: 1390-860X

Assembly of Automotive Seatbelts Assisted by Cobot and RoboDK

Ensamblaje de cinturones de seguridad vehiculares asistido por cobot y RoboDK

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Received: 04-09-2025, Received after review: 15-01-2026, Accepted: 21-04-2026, Published: 01-07-2026

Abstract

In the modern automotive sector, Industry 4.0 principles have been widely adopted to enhance flexibility, efficiency, and quality in production processes. Nonetheless, several automotive subprocesses still rely on operators for manual or repetitive tasks, which are highly susceptible to human error and may compromise product quality while increasing operating costs . This study addresses this challenge by implementing a collaborative robotic solution for manufacturing environments. Specifically, it proposes the integration of a cobot for the assembly of automotive seatbelts at the ZF plant in Tamaulipas, Mexico. RoboDK is used to simulate and evaluate a Universal Robots cobot intended to increase operational efficiency and reduce defect rates at the press station. The results demonstrate the feasibility of the proposed simulation approach, enabling the functional analysis and validation of multiple configurations within the manufacturing cell while ensuring the safe integration of the collaborative robot (cobot). Furthermore, the proposed solution supports safe human-robot collaboration in compliance with the ISO/TS 15066 technical specification. Overall, the implemented system shows significant potential to improve efficiency and operational flexibility while reducing costs in the production process.

Keywords: automotive industry, Industry 4.0, collaborative robotics, cobot, digital simulation, RoboDK, Universal Robots.

Resumen

En la industria automotriz moderna se han adoptado de manera extensiva diferentes principios y paradigmas de la Industria 4.0 para mejorar la flexibilidad, eficiencia y calidad en sus procesos. Sin embargo, son varios los subprocesos en este sector industrial que aún dependen de los operarios y de tareas manuales o repetitivas, las cuales suelen ser altamente susceptibles a errores humanos que impactan negativamente en la calidad del producto final e implican elevados sobrecostos de operación. El presente estudio atiende dicha problemática mediante un enfoque de robótica colaborativa aplicado a celdas de manufactura y propone la integración de un cobot para el ensamblado de los cinturones de seguridad automovilísticos en la planta de ZF en Tamaulipas, México. La propuesta utiliza RoboDK para simular y evaluar la implementación de un cobot de Universal Robots con el propósito de aumentar la eficiencia operativa y reducir la tasa de defectos en la estación de prensa. Los resultados obtenidos demuestran la viabilidad de la simulación y permiten llevar a cabo el análisis funcional y la validación de las configuraciones en la celda de manufactura a partir de la integración segura del cobot, garantizando el cumplimiento de la especificación técnica ISO/TS 15066. El sistema implementado muestra un potencial significativo en cuanto a eficiencia, flexibilidad operacional y reducción de costos en el proceso productivo.

Palabras clave: industria automotriz, industria 4.0, robótica colaborativa, RoboDK, Universal Robots, simulación digital.

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Suggested citation: K. O. Manzano-Ibarra, I. O. Benítez-González and J. M. Bernal-de Lázaro. “Assembly of Automotive Seatbelts Assisted by Cobot and RoboDK,” *Ingenius, Revista de Ciencia y Tecnología*, N.° 36, pp. 9-17, 2026, doi: https://doi.org/10.17163/ings.n36.2026.01.

1. Introduction

Industry 4.0 has had a significant impact on the automotive sector. Historically, this field has pioneered the adoption of emerging technologies, including intelligent control systems [1–4], robotics [5, 6], and augmented reality [7], to increase productivity, flexibility, and efficiency in the manufacturing of parts and components. In this context, collaborative robotics, as one of the pillars of Industry 4.0, has enabled the automation of complex tasks, including machine tending, assembly processes such as screwing and part insertion, sealing, bonding, surface finishing, welding, and quality control [8].

Within the current international regulatory framework established by the ISO/TS 15066 technical specification, the concept of a collaborative robot has been refined by emphasizing that collaboration is not an intrinsic property of the robot itself, but rather a characteristic of the application or task being performed. In this context, it is more accurate to refer to collaborative applications or tasks, in which an industrial robot interacts with humans under specific safety modes and criteria, such as monitored stop, hand guiding, speed and separation monitoring, and power and force limiting. Consequently, the same robot may or may not be involved in a collaborative application depending on the environment, the end effector, and the operating conditions. Together with ease of programming, this application-based understanding of collaboration facilitates human-machine interaction and provides greater adaptability to different industrial environments and occupational safety requirements. These advantages have contributed to the recent growth of collaborative robot applications in the automotive sector [8–11].

Accordingly, approximately 70% of automotive production units currently integrate industrial robots configured to perform collaborative tasks under safe operating modes that enhance process flexibility and efficiency. In this context, nearly 50% of small and medium-sized enterprises are implementing pilot installations to address for labor shortages and improve operational performance [10, 11].

This high level of interest has led to the availability of a wide range of industrial solutions in the collaborative robotics market. Among these, Universal Robots' e-Series stands out, alongside solutions offered by other major providers such as KUKA, Yaskawa Electric Corporation, ABB, and Fanuc Corporation.

Although cobot-based solutions have become an attractive option for companies seeking to improve the efficiency, quality, and safety of their processes, their implementation still requires trained personnel and adequate infrastructure. Compared with conventional robots, which typically occupy more space, require more complex programming, and operate from fixed positions, cobots offer greater flexibility, safety, and ease of programming. Their compact design also allows them to be repositioned more easily within the production environment [12–14].

Robotic simulations are essential for evaluating possible configurations in these systems without exposing operators, infrastructure, or the robot itself to potential hazards in the work area. Simulation-based design enables effective integration by reducing the time and costs associated with production line downtime and allowing automated processes to be optimized before physical implementation [15]. In this context, RoboDK is an appropriate tool because it provides intuitive simulation software for robotic arms and does not require advanced programming knowledge.

At the bar pressing workstation located at the ZF plant in Reynosa, improper positioning of the bars within the part was identified as a recurring problem, leading to defective pressing operations and material loss. Additionally, this production environment involves frequent interaction with other personnel and limited physical space. Therefore, automating this process requires a collaborative robotics solution based on a compact robotic arm with strong human-machine interaction capabilities, designed to increase production line efficiency and reduce improper material handling.

This article evaluates the implementation of a Universal Robots cobot for the production of automotive seatbelts using a comparative analysis and robotic simulation approach supported by RoboDK software. These simulations enable the identification of suitable cobot configurations, making it possible to improve efficiency, quality, and safety indicators at the bar pressing workstation without significantly affecting the workspace, while ensuring compliance with the current international regulatory framework established by the ISO/TS 15066 technical specification.

2. Materials and Methods

This section describes the research methodology, process analysis, and study phases.

2.1. Research Approach, Methodology, and Phases

The solution presented in this article employs a hybrid methodology based on comparative analysis and simulation to support the selection and implementation of a cobot to automate the production of automotive seatbelts. In this context, comparative analysis is understood as a research method that involves collecting, comparing, and analyzing qualitative and quantitative data to provide a clearer representation of the characteristics of processes, documents, or other study objects, supported by visual tools that facilitate their evaluation.

For the development of this research, several instruments were used, including: (i) technical datasheets of Universal Robots cobots, (ii) RoboDK software operation manuals, and (iii) CAD and 3D models developed in Fusion 360, considering the workspace of the bar pressing station. To achieve the objectives of this study, qualitative and quantitative analyses of the work environment were also performed to select the most suitable cobot and validate its implementation through digital simulation. The main techniques used were as follows:

1. Documentary review: used to analyze the specifications of Universal Robots cobot models.
2. Comparative analysis: used to compare technical and economic criteria through comparative tables as an evaluation tool.
3. Digital simulation: performed using RoboDK and Fusion 360 to model the work environment, program trajectories, measure cycle times, identify environmental interferences, and validate cobot operability.

The data analysis in this research was structured into three main stages. First, a technical comparison of the different cobot models offered by Universal Robots was conducted, considering specifications such as payload, workspace, repeatability, and cost. This comparison was essential to avoid oversizing the future integration investment. In the second stage, a digital simulation of the selected cobot model was developed using RoboDK software. This step analyzed key parameters such as cycle time, potential collisions, and the feasibility of integrating the cobot into the actual workspace of the bar pressing station. Finally, the simulation results were compared with the actual process conditions to validate the applicability of the proposed solution.

In industrial automation, particularly in the selection of collaborative robotic arms, comparative analysis and digital simulation play an essential role in the early stages of a project. These techniques are complementary: comparative analysis supports the evaluation and selection of the most suitable model based on the required technical specifications, while digital simulation facilitates the visualization and validation of different configurations for integrating the cobot into the workspace. This methodology makes it possible to identify the most viable option for cobot implementation without significantly interfering with the production line, while reducing risks, costs, and time associated with physical testing. As previously stated, the main objective of the methodology is to select and evaluate a cobot by collecting and analyzing technical data from Universal Robots collaborative robot models. The phases comprising the comparative analysis in this case are shown in Figure 1 and described below.

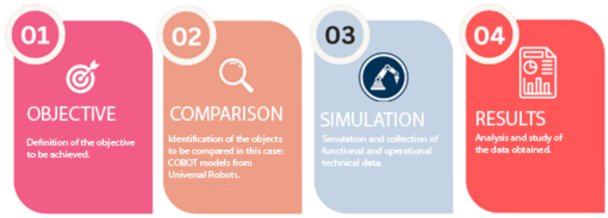


Figure 1. Phases of the comparative analysis.

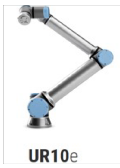
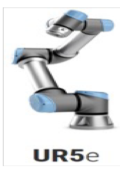
2.2. Considerations for Cobot Selection

Since the application does not require a high payload capacity, several e-Series cobots offered by Universal Robots were evaluated. Table 1 summarizes and compares the Universal Robots models considered in this study. The weight of both the end effector and the product was also considered as a determining factor for positioning the robot within the bar pressing station. For end-effector selection, technical information from ROBOTIQ was reviewed, considering not only the total product weight of 1.2 kg, but also the effective mass transmitted to the end effector during the gripping operation. This effective mass depends on the contact geometry, force distribution among the fingers, and task configuration. Thus, the gravitational force associated with the effective mass can be expressed as equation (1):

$$F_g = m_{ef} \cdot g \tag{1}$$

where F_g is the gravitational force applied at the gripping point, m_{ef} is the effective mass supported by the end-effector contact, and g is the acceleration due to gravity. Based on the component geometry, the type of gripping, and the load distribution recommended by the manufacturer, the effective mass transmitted to each contact point was estimated at 0.345 kg. To ensure a secure grip and compensate for possible dynamic effects and operational variations, a safety factor of 2 was subsequently applied, resulting in a minimum required force of 6.77 N. Based on this analysis, the proposed solution incorporates the Hand-E end effector from ROBOTIQ, as shown in Figure 2(a).

Table 1. Technical comparison of Universal Robots e-Series models

Models	Payload útil (kg)	Reach (mm)	Repeatability (mm)	Degrees of freedom	Communication	Control	Cost (USD)
	16 kg	900 mm	± 0.05 mm	6 joints	Control frequency 500 Hz Modbus TCP PROFINET Ethernet/IP USB 2.0, USB 3.0	Polyscope	57,600
	12.5 kg	1300 mm	± 0.05 mm	6 joints	Control frequency 500 Hz Modbus TCP PROFINET Ethernet/IP USB 2.0, USB 3.0	Polyscope	47,600
	5 kg	850 mm	± 0.03 mm	6 joints	Control frequency 500 Hz Modbus TCP PROFINET Ethernet/IP USB 2.0, USB 3.0	Polyscope	38,300
	3 kg	500 mm	± 0.03 mm	6 joints	Control frequency 500 Hz Modbus TCP PROFINET Ethernet/IP USB 2.0, USB 3.0	Polyscope	33,000

(a) (b) (c)

Figure 2. (a) Hand-E end effector, (b) Retractor 4.0, and (c) Proposed Hand-E design.

This model meets requirements of the application, offering design flexibility, a 7 kg payload capacity, adequate precision, and a gripping force ranging from 20 to 185 N [16]. Figure 2(b) shows the positions that the end-effector fingers must reach on the product to be handled. Since the original Hand-E design cannot access these areas, a modified finger design was developed in Fusion 360. The final design, shown in Figure 2(c), provides an adequate grip. Based on this analysis and the available options from Universal Robots, the UR3e model was selected as the most viable alternative because of its compact design and 3 kg payload capacity [17], which is sufficient to handle the combined weight of the part and the end effector without difficulty.

2.3. 3D Modeling

Before creating the simulation environment, the 3D models of the elements to be evaluated were obtained, including the robot workstation, the bar pressing station, the collaborative robot, and the end effector. Autodesk Fusion 360 was used as the CAD design software to model the UR3e workstation together with the bar pressing station [18–20]. Figure 3 shows the UR3e collaborative robot model and the selected end effector from the RoboDK library.

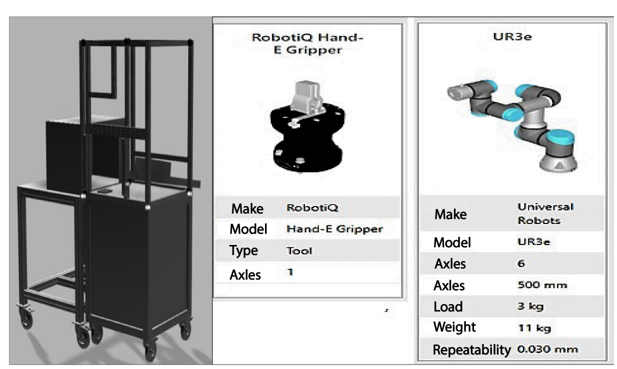
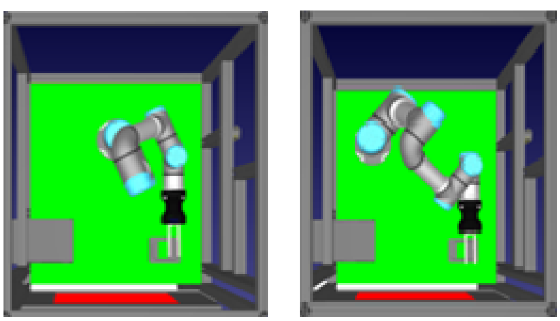


Figure 3. 3D model of the UR3e workstation with the bar pressing station and end effector.

3. Results and Discussion

Before programming the trajectories and confirming the final robot selection, simulations were performed to evaluate different alternatives for positioning the base of the UR3e cobot at the bar pressing station. Initially, two configurations were considered: a central location on the worktable and a second option at one of the table corners. As shown in Figure 4, the first alternative limited the robot's mobility and effective reach, whereas the second provided greater freedom of movement and reduced the risk of collisions with the surrounding environment. Once the optimal table-corner location was defined, the initial position of the UR3e was established and the trajectories were configured. The starting position was set at the fixture where the operator manually places the part, as illustrated in Figure 5.



(a) (b)

Figure 4. Possible locations for the UR3e base.

Once the initial conditions are met, the UR3e executes a linear downward motion (MoveL) until it reaches the gripping point, ensuring greater precision and minimizing the risk of collision with the product. Upon reaching the programmed point, the end effector is activated to grasp the retractor. Since the part is placed on a fixture, an additional motion was included to extract the component. Once the part has been picked up, the cobot moves toward the bar pressing station, which uses two fixtures. To correctly position the part in this station, a sequence of three motions was configured, combining joint movements (MoveJ) for general positioning and linear movements (MoveL) for the final approach and precise placement of the part on the press fixture.

For safety reasons, withdrawal of the UR3e from the press area was explicitly programmed as part of the operational cycle. After the pressing operation is completed, the UR3e grasps the part again through a linear motion and moves it to the next programmed position. During part removal, the cobot position is defined to avoid collisions and allow subsequent unloading. Finally, the cobot positions the finished part above the discharge tray. In this case, a joint movement (MoveJ) was used because it allows faster motion and does not require high precision, since the tray has sufficient space to properly receive the part.

The complete task was implemented using a set of 7 to 9 waypoints, including the start, approach, gripping, lifting, placement, safe withdrawal, and unloading positions. With the proposed trajectory, the robot cycle time was 5.8 s, excluding the inherent cycle time of the bar pressing station. Therefore, this station cycle had to be added to obtain a realistic estimate of the total process time. Since the bar pressing station has a cycle time of 3.94 s, the total estimated cycle time with the UR3e was 9.34 s. In addition, potential collisions between the UR3e and the work environment were evaluated.

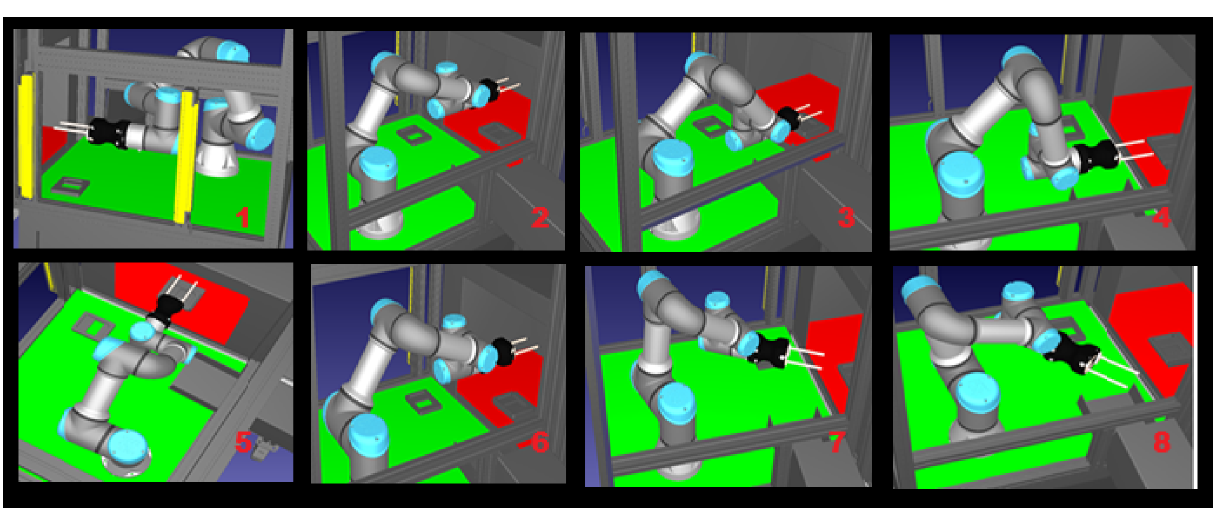


Figure 5. Sequence of programmed motions for the cobot at the bar pressing station.

3.1. Integration and Validation in a Real Environment

To validate the simulation results and the proposed designs, tests were conducted on production line 454 to evaluate the performance of the UR3e collaborative robot. Figure 6 shows the bar pressing workstation before and after UR3e integration on production line 454. Based on the position recommended by the RoboDK simulation, the workstation was installed at the bar pressing station, and the position of the UR3e base on the workstation was verified. The robot was then integrated and programmed into the production line according to the simulation results, as shown in Figure 5. In addition, the UR3e program was integrated with the programmable logic controller of the bar pressing station.

First, the cobot startup was verified. Upon receiving a signal indicating the presence of a part on the fixture, the cobot initiated its cycle and accurately grasped the part. The part was then extracted from the fixture before the cobot moved to the next trajectory point. As previously defined in the simulation, the UR3e executed a backward motion to maintain a safe distance while the bar pressing station was operating. Once the pressing cycle was completed, the UR3e moved to the next trajectory point to grasp and remove the part from the station, positioning it for subsequent unloading into the discharge tray. To complete the sequence, the UR3e reached the final programmed position, deactivated the end effector, and released the part into the output tray.

(a) (b)

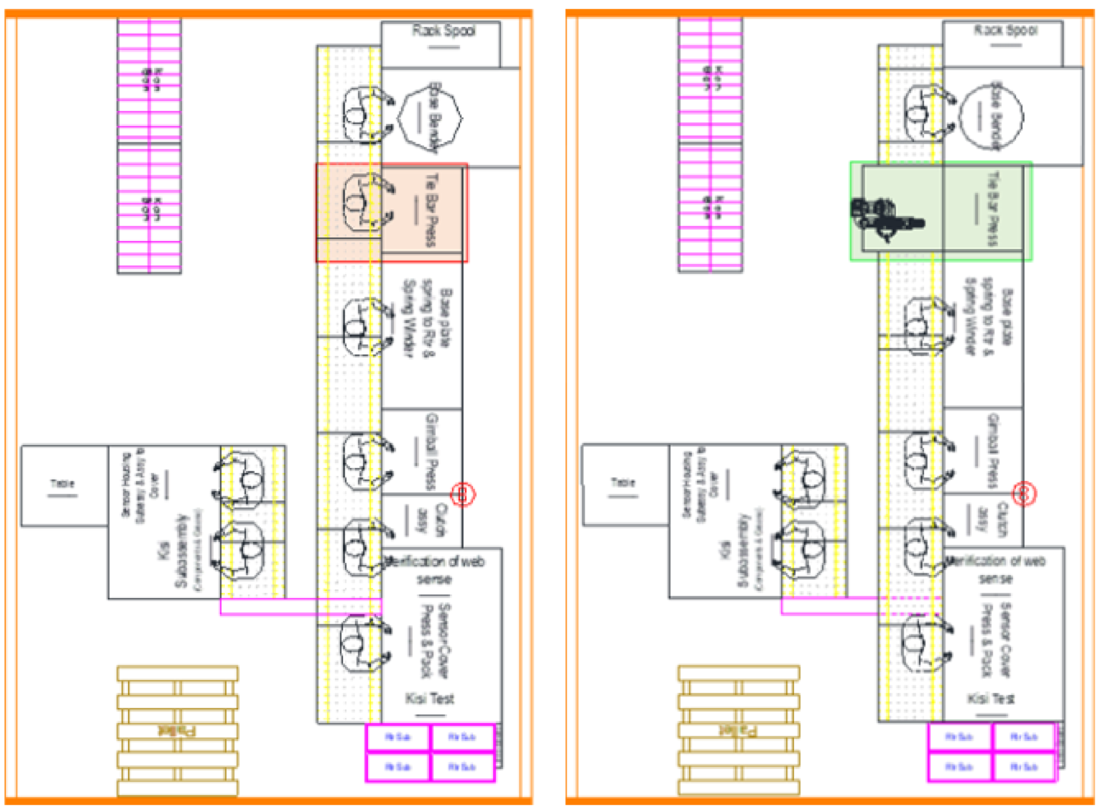
Figure 6. Real implementation of the proposed solution at the bar pressing station on production line 454: (a) before UR3e cobot integration and (b) after UR3e cobot integration.

3.2. Results of the UR3e Integration

This section presents a comparative analysis of process efficiency after incorporating the proposed UR3e collaborative robot into the bar pressing station. For this analysis, 10 samples of process cycle times were recorded for both manual operation and cobot-assisted operation. Table 2 presents the results obtained from this comparison. Manual operation times were measured under normal workflow conditions during a standard production shift, avoiding situations of extreme fatigue or conditions that were not representative of the actual process. The measurements were obtained from an experienced operator previously trained at the bar pressing station to ensure consistency in task execution and reduce variability associated with individual differences. This approach enabled a direct and controlled comparison between manual and automated performance in a realistic industrial scenario. Each sample corresponded to one operation shift, during which multiple consecutive cycles were recorded. Thus, the intrashift variability captured by the standard deviation naturally reflects the effects of fatigue, microbreaks, and adjustments inherent to manual operation, whereas the comparison with the cobot highlights differences in process repeatability and consistency.

This methodology was deliberately adopted to ensure a fair and representative comparison between the two modes of operation while keeping environmental conditions and workload constant. To evaluate whether the observed reduction in cycle time was statistically significant, an independent-samples Student's t-test was applied, considering the mean values per operation shift as the experimental units ($n = 10$ per condition).

The results indicate a statistically significant difference between manual operation and UR3e-assisted operation ($p < 0.05$), confirming that the reduction in cycle time was not attributable to random process variability, but rather to a systematic effect associated with the integration of the collaborative robot. The time measurements confirmed the feasibility of integrating a cobot into the bar pressing station process. Process efficiency improved significantly compared with the previous manual operation, reducing the average cycle time from 13.04 s to 9.34 s. Similarly, the cycle time obtained in the simulation was consistent with that observed in the real application, demonstrating repeatable and stable process execution. Figure 7(a) shows the layout before cobot integration, while Figure 7(b) illustrates the layout after the integration of the collaborative robot into production line 454. As shown in Figure 7, the UR3e operates within a delimited area. However, this configuration does not imply an isolated environment, but rather a functional organization of the workspace that enables safe coexistence between the human operator and the robot throughout the work cycle. During the automatic operation phases, the UR3e-based system operates with the required physical separation to ensure safety and process repeatability.



(a) (b)

Figure 7. Production line and workstation with human–machine interaction: (a) Layout of line 454 before UR3e cobot integration and operation, (b) Layout of line 454 after UR3e cobot integration and operation.

Table 2. Average cycle times before and after UR3e cobot integration.

	Cycle times (s)										
Elements	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**Prom.**
Operator	13.19±0.28	13.25±0.31	12.85±0.35	12.68±0.33	13.02±0.29	13.17±0.30	12.95±0.34	12.84±0.36	13.25±0.32	13.15±0.27	13.04±0.20
UR3e	9.38±0.05	9.31±0.04	9.30±0.06	9.43±0.05	9.31±0.04	9.35±0.05	9.33±0.04	9.31±0.05	9.31±0.04	9.33±0.05	9.34±0.04
Statistical test					**t-statistic**		**gl**			**p-value**	
Student's t-test (independent samples)					t = 56.4		18			p<0.001	

In contrast, during loading, unloading, adjustment, programming, maintenance, and supervision, the robot can operate in safe modes, such as monitored stop or hand guiding, allowing direct operator intervention in accordance with the criteria defined in ISO/TS 15066 [21]. Therefore, the addressed task corresponds to a sequential collaborative application in which the human operator and the robot share the workspace and cooperate within the production flow, although they do not perform simultaneous actions on the same part. The collaborative nature of the application lies primarily in the operational flexibility it provides, allowing safe switching between automatic and collaborative modes depending on the process stage. Thus, the robot performs operations that require precision, repeatability, and control, while the operator remains responsible for feeding, supervision, and process control, reducing physical workload and operational variability. Likewise, the visual delimitation of the robot's operating area responds to criteria related to speed control, separation, and power and force limiting, in accordance with ISO/TS 15066, rather than to physical isolation incompatible with a collaborative application.

4. Conclusions

The analysis of the results confirmed the initial hypothesis that integrating a Universal Robots cobot at the bar pressing station improves the production process in terms of efficiency, quality, and safety without significantly affecting the workspace. The results also validate the use of RoboDK as a simulation tool to support the design and evaluation of the proposed system. The suitability of the selected robotic arm was demonstrated by the reduction in average cycle time from 13.04 s to 9.34 s. Additionally, the execution of repeatable and controlled trajectories contributes to reducing the risk of material damage during handling by minimizing positioning errors and the variability inherent to manual operation. The methodological approach presented in this study is scalable and transferable to other production-line stations involving repetitive handling tasks. By adapting the layout, defining new trajectories, and selecting the appropriate end effector, the same simulation-based procedure can be applied to operations such as machine loading and unloading, inspection, or light assembly, enabling prior validation of system performance and its impact on cycle time, safety, and process quality.

Conflict of Interest

The authors declare that they have no potential conflicts of interest to disclose in relation to this article.

Acknowledgments

The authors acknowledge the financial support provided by FAPERJ, Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro, Brazil. Senior Postdoctoral Fellowship (PDS), FAPERJ Call No. 18/2024.

Contributor Roles

- **Kevyn Obed Manzano-Ibarra:** Conceptualization, data curation, formal analysis, research, methodology, project management, software, validation, visualization, writing – original draft.
- **Ivón Oristela Benítez-González:** Conceptualization, data curation, methodology, project management, validation, visualization, writing – review and editing.
- **José Manuel Bernal-de Lázaro:** Conceptualization, data curation, research, methodology, project management, validation, visualization, writing – review and editing.

References

[1] Y. Han, J. Shao, R. Zhou, Y. Liao, and Y. Zhong, "Robotic digital twin based full lifecycle decision framework for automotive productions," *IEEE Network*, vol. 39, no. 4, pp. 173–181, 2025. [Online]. Available: https://doi.org/10.1109/MNET.2024.3418624

[2] J. Yang, Y. H. Son, D. Lee, and S. D. Noh, "Digital twin-based integrated assessment of flexible and reconfigurable automotive part production lines," *Machines*, vol. 10, no. 2, p. 75, Jan. 2022. [Online]. Available: https://doi.org/10.3390/machines10020075

[3] O. Llanes-Santiago, A. Prieto-Moreno, J. M. Bernal de Lázaro, D. C. Knupp, and A. J. Silva Neto, "A design proposal for multiblock-based fault diagnosis systems in complex industrial plants," *Chemometrics and Intelligent Laboratory Systems*, vol. 162, pp. 149–159, Mar. 2017. [Online]. Available: https://doi.org/10.1016/j.chemolab.2017.01.015

[4] A. S. Bisen and H. Payal, "Collaborative robots for industrial tasks: A review," *Materials Today: Proceedings*, vol. 52, pp. 500–504, 2022. [Online]. Available: https://doi.org/10.1016/j.matpr.2021.09.263

[5] L. Liu, F. Guo, Z. Zou, and V. G. Duffy, "Application, development and future opportunities of collaborative robots (cobots) in manufacturing:

A literature review," *International Journal of Human–Computer Interaction*, vol. 40, no. 4, pp. 915–932, Apr. 2022. [Online]. Available: https://doi.org/10.1080/10447318.2022.2041907

[6] C. E. Martínez-Ochoa, I. O. Benítez-González, A. O. Cepero-Díaz, J. R. Núñez-Álvarez, C. G. Miguélez-Machado, and Y. E. Llosas-Albuerne, "Active disturbance rejection control for robot manipulator," *Journal of Robotics and Control (JRC)*, vol. 3, no. 5, pp. 622–632, 2022. [Online]. Available: https://doi.org/10.18196/jrc.v3i5.14791

[7] R. G. Boboc, F. Gîrbacia, and E. V. Butilă, "The application of augmented reality in the automotive industry: A systematic literature review," *Applied Sciences*, vol. 10, no. 12, p. 4259, 2020. [Online]. Available: https://doi.org/10.3390/app10124259

[8] A. Keshvarparast, D. Battini, O. Battaia, and A. Pirayesh, "Collaborative robots in manufacturing and assembly systems: literature review and future research agenda," *Journal of Intelligent Manufacturing*, vol. 35, no. 5, pp. 2065–2118, May 2023. [Online]. Available: https://doi.org/10.1007/s10845-023-02137-w

[9] GGI, *Collaborative Robots Market.* Global Growth Insights, 2024. [Online]. Available: https://upsalesiana.ec/ing36ar1r9

[10] GVR, *Collaborative Robot Market (2026–2033) Size, Share & Trends Analysis Report.* Grand View Research, 2026. [Online]. Available: https://upsalesiana.ec/ing36ar1r10

[11] MI, *Tamaño del mercado de robots colaborativos y análisis de participación tendencias de crecimiento y pronósticos (2024-2029).* Mordor Intelligence, 2024. [Online]. Available: https://upsalesiana.ec/ing36ar1r11

[12] P. Amiri, M. Müller, M. Southgate, T. Theodoridis, G. Wei, M. Richards-Brown, and W. Holderbaum, "A statistical analysis of commercial articulated industrial robots and cobots," *Journal of Manufacturing and Materials Processing*, vol. 8, no. 5, p. 216, 2024. [Online]. Available: https://doi.org/10.3390/jmmp8050216

[13] J. Bernal-de Lázaro, O. Llanes-Santiago, A. Prieto-Moreno, A. del Castillo-Serpa, and A. Silva-Neto, "A novel index for the robustness comparison of classifiers in fault diagnosis," *Neurocomputing*, vol. 275, pp. 636–648, Jan. 2018. [Online]. Available: https://doi.org/10.1016/j.neucom.2017.09.021

[14] V. Villani, F. Pini, F. Leali, and C. Secchi, "Survey on human–robot collaboration in industrial settings: Safety, intuitive interfaces and applications," *Mechatronics*, vol. 55, pp. 248–266, Nov. 2018. [Online]. Available: https://doi.org/10.1016/j.mechatronics.2018.02.009

[15] Siemens. (2026) Simulación robótica. Siemens. [Online]. Available: https://upsalesiana.ec/ing36ar1r15

[16] Robotiq. (2026) Hande-E. Robotiq. [Online]. Available: https://upsalesiana.ec/ing36ar1r16

[17] U. Robots. (2026) e-Series. Universal Robots. [Online]. Available: https://upsalesiana.ec/ing36ar1r17

[18] RoboDK. (2026) Software de simulación de robots. RoboDK. [Online]. Available: https://upsalesiana.ec/ing36ar1r18

[19] N. A. Molina Ferrer, *Diseño de interfaz y comunicación para inspecciones visuales automatizadas en ensamblajes complejos mediante un Cobot Festo.* Universitat Politècnica de València, 2024. [Online]. Available: https://upsalesiana.ec/ing36ar1r19

[20] N. P. Brito Santos, *Diseño y simulación de un sistema automatizado para la navegación y almacenamiento eficiente de paquetes en centros logísticos utilizando el Robot Colaborativo UR10e en conjunto con un Robot Móvil y la integración de visión artificial y marcadores ArUco mediante la herramienta CoppeliaSim (V-REP)".* Universidad Miguel Hernández de Elche, 2023. [Online]. Available: https://upsalesiana.ec/ing36ar1r20

[21] ISO, *ISO/TS 15066:2016 Robots and robotic devices – Collaborative robots.* International Organization for Standardization, 2016. [Online]. Available: https://upsalesiana.ec/ing36ar1r21