INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH AND INNOVATIVE STUDIES

IJSRIS journal

ISSN: 2820-7157

Advancing Knowledge, Inspiring Innovation

www.ijsrisjournal.com

INDEXED JOURNAL

PEER REVIEWED Rigorous & Transparent | DOI: CROSSREF Member | OPEN ACCESS For Global Visibility | BI-MONTHLY Timely Publication | WIDE READERSHIP High Impact & Visibility | AUTHOR FRIENDLY Fast | Supportive | Reliable

RECEIVED 19 June 2026 | ACCEPTED 10 July 2026 | PUBLISHED 1 August 2026

August 2026 | Volume 5 | Number 4

Pages from: 698 to 707

# The contribution of artificial intelligence and humanoid robotics to improving productivity, quality and safety in industry 4.0

**KAPALALA KAPENDA Blaise**[1] **Yves NSOTA OLANG**[2]

1PhD Student, Department of Computer Science, Institut Supérieur Pédagogique de la Gombe, City and Province of Kinshasa, Democratic Republic of the Congo, blaisekapalala94@gmail.com , +243 811 459 397

2 Higher Institute of Commerce of Idiofa (ISC-IDIOFA), Democratic Republic of the Congo. yvesolang2016@gmail.com



Crossref doi

PREFIX : 10.63883

IJSRIS JOURNAL



## ABSTRACT

The digital transformation of industry is characterised by the increasing integration of technologies such as artificial intelligence, the Industrial Internet of Things, cyber-physical systems, digital twins, big data and intelligent robotics. In this environment, humanoid robots are gradually emerging as a new category of systems capable of interacting with infrastructure originally designed for humans. Their combination with artificial intelligence opens up new possibilities for the flexible automation of production, handling, assembly, quality control and maintenance activities.

This article analyses the potential and currently observable contribution of artificial intelligence and humanoid robotics to three fundamental dimensions of industrial performance: productivity, quality and safety. The study is based primarily

on an analytical review of recent scientific and institutional literature, supplemented by the development of a conceptual model linking artificial intelligence, robotic capabilities, human–robot collaboration and industrial performance.

The analysis shows that techniques such as machine learning, computer vision, deep learning, natural language processing and intelligent planning can enhance the autonomy and adaptability of robots. However, empirical evidence focusing exclusively on humanoids remains more limited than that concerning conventional and collaborative industrial robots.

**Keywords:** Artificial intelligence; humanoid robot; collaborative robotics; Industry 4.0; productivity; quality; industrial safety; smart factory; human-robot collaboration.

## 1. Introduction

### 1.1. Background to the study

For several years now, global industry has been undergoing a profound transformation driven by the use of advanced digital technologies. This development is generally grouped under the concept of Industry 4.0, which refers to the integration of digital technologies into production systems in order to create industrial environments that are connected, automated, intelligent and capable of adapting rapidly to change.

- Artificial intelligence;
- Machine Learning;
- Deep learning;
- Computer vision;
- The Industrial Internet of Things;
- Cyber-physical systems;
- Digital twins;
- Cloud computing and edge computing;
- Big Data;
- Industrial and collaborative robotics;
- Autonomous systems.

Artificial intelligence now plays a cross-cutting role. Gao et al. (2024) note that its applications in manufacturing include, in particular, the design of production systems, planning, process modelling and optimisation, quality assurance, maintenance, and automated assembly and disassembly.


**Figure 1.** The industry 4.0 technology ecosystem.

At the same time, industrial robotisation is experiencing significant growth. According to the International Federation of Robotics (IFR, 2024), more than four million industrial robots were in operation in factories worldwide in 2023. Interest in humanoid robots is also growing, although this technology remains in the experimental and development phase in several sectors.

### 1.2. Research Question

Industrial companies need to produce faster, reduce costs, minimise downtime, improve quality, limit defects, protect workers and increase production flexibility. Traditional automation meets some of these requirements, but is often tied to fixed workstations and predetermined tasks.

Humanoid robots offer a different approach. Their design is intended to enable them to operate in environments designed for humans, to use certain existing tools and to interact with equipment already in place. However, their integration raises issues of reliability, safety, costs, cybersecurity, social acceptability and liability.

The main question of this research is therefore as follows: To what extent can the integration of artificial intelligence and humanoid robotics help to simultaneously improve the productivity, quality and safety of production systems in the context of Industry 4.0?

How does artificial intelligence enhance the autonomy and adaptability of humanoid robots in an industrial environment?

To what extent can these technologies improve industrial productivity?

How can they contribute to quality control and improvement?

Under what conditions can they help reduce human exposure to hazardous activities?

What technical, economic, organisational, social and safety barriers are limiting their industrial adoption?

## 2. Objectives of the study

### 2.1. General objective

The general objective of this research is to analyse the contribution of artificial intelligence and humanoid robotics to improving productivity, quality and safety in industrial systems within the scope of Industry 4.0.

### 2.2. Specific objectives

To present the fundamental concepts of Industry 4.0, artificial intelligence and humanoid robotics.

To analyse the main artificial intelligence technologies integrated into intelligent robots.

To identify potential and emerging industrial applications of humanoids.

To assess their potential contribution to productivity.

To examine the role of AI and robotics in improving quality control.

To analyse their contribution to worker safety.

Identify the risks and obstacles associated with their integration.

Propose a conceptual model for measuring their influence on industrial performance.

## 3. Research hypotheses

### H1: Artificial intelligence and productivity

The integration of artificial intelligence into humanoid robotic systems has a positive impact on industrial productivity.

### H2: Artificial Intelligence, Robotics and Quality

The combined use of artificial intelligence, computer vision and intelligent robotics improves anomaly detection and product quality.

### H3: Humanoid Robotics and Safety

Assigning intelligent robots to dangerous, repetitive or physically demanding tasks reduces workers' exposure to industrial risks.

### H4: Human-robot collaboration

Properly designed human-robot collaboration further improves overall performance compared to an approach relying exclusively on automation or exclusively on manual labour.

## 4. Literature review

### 4.1. Industry 4.0

Industry 4.0 refers to a smart manufacturing paradigm based on the convergence of the physical and digital worlds. Machines, operators, products and IT systems communicate via connected infrastructure. An Industry 4.0 factory relies on the constant flow of data to monitor machines, detect anomalies, predict breakdowns and optimise decision-making.

### 4.2. Artificial intelligence applied to industry

Artificial intelligence encompasses a set of methods enabling computer systems to perform tasks related to perception, learning, prediction, planning and decision-making. In industry, it relies in particular on machine learning, deep learning, computer vision and, more recently, natural language processing.

#### 4.2.1. Machine learning

Machine learning enables the creation of predictive models based on historical data. It can be used to predict a breakdown, identify a fault, anticipate a maintenance requirement, forecast demand or optimise process parameters.

#### 4.2.2. Deep Learning

Deep learning relies on deep neural networks capable of automatically extracting complex representations from large amounts of data. In industry, it is used in particular for object recognition, image classification, fault detection, video analysis and trajectory estimation.

#### 4.2.3. Computer Vision

Computer vision enables a robot to interpret information from cameras and 3D sensors. It can be used to identify a part, check its orientation, detect a defect, locate an operator and adjust the robot's trajectory.

#### 4.2.4. Natural Language Processing

The integration of language models into robotic systems paves the way for more intuitive interactions between operators and robots. Yu, Zhang and Shi (2026) demonstrate that these approaches can facilitate the understanding of instructions expressed in natural language and support the planning of industrial tasks.

## 5. Humanoid robotics

### 5.1. Definition

A humanoid robot is a robotic system whose structure or certain functions are modelled on the human body. It may comprise a head, a torso, arms, hands or grippers, legs or a mobile base, as well as various sensors. The industrial appeal of this architecture lies, in particular, in its potential compatibility with human workplaces.

### 5.2. From programmed robots to cognitive robots

Conventional industrial robots mainly carry out predetermined movements. Intelligent robots, by contrast, tend towards a cognitive loop of the following type: Perception → Understanding → Decision → Action → Learning. This development enables them to adapt more effectively to changes in the environment.

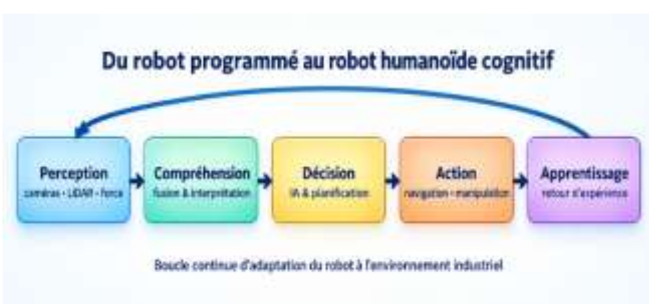


**Figure 2.** Cognitive loop of an intelligent humanoid robot.

## 6. Integration of ai and humanoid robots in the smart factory

A functional architecture can be designed around the following chain: Industrial environment → Sensors / Cameras / IoT → Data collection → Artificial intelligence → Perception and analysis → Planning and decision-making → Humanoid robot → Industrial action → Data feedback and learning.

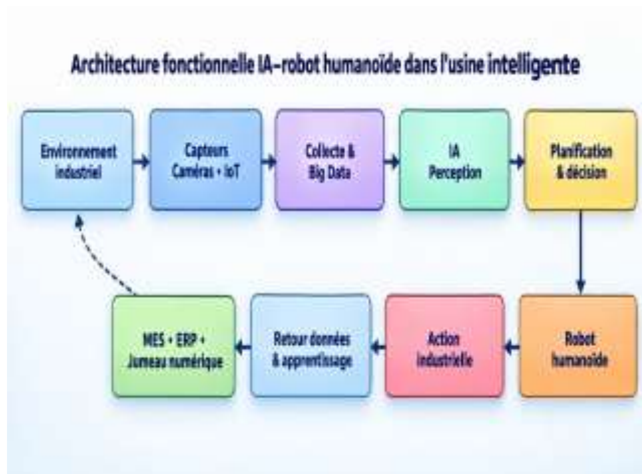


**Figure 3.** Functional architecture for AI–humanoid robots in the smart factory.

This architecture can be connected to the ERP system, the MES, maintenance systems, programmable logic controllers, machine tools, digital twins and IoT platforms. In particular, the digital twin can be used to virtually test human–robot collaboration prior to its physical deployment.

## 7. Contribution to industrial productivity

### 7.1. Automation of repetitive tasks

Humanoids can be assigned to tasks such as loading and unloading, handling parts, sorting, moving materials, feeding machines, assembly, order picking and inspection.

### 7.2. Reduction in cycle time

Through automatic planning and trajectory optimisation, artificial intelligence can help to reduce certain cycle times. Cycle time can be defined by the equation: $Tc = Tp / N$, where $Tc$ represents the cycle time, $Tp$ the total production time and $N$ the number of units produced.

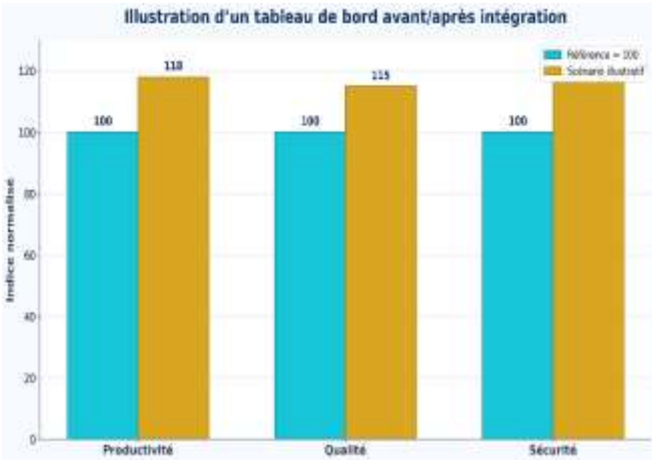


**Figure 4.** Illustrative performance dashboard. Fictitious standardised values, to be replaced by empirical data.

### 7.3. Operational availability and predictive maintenance

AI can monitor temperature, vibrations, power consumption, the condition of joints, sensors and batteries. This data feeds into predictive maintenance models, enabling the detection of early warning signs of failure and helping to minimise unplanned downtime.

### 7.4. Production flexibility

Flexibility is one of the theoretical advantages of humanoids: they are designed to operate in existing spaces, handle tools intended for human use, and be reprogrammed for various tasks without requiring a complete overhaul of the production line.

## 8. Contribution to quality improvement

### 8.1. Automated inspection

The combination of robots, cameras and artificial intelligence enables automatic checks to be carried out on dimensions, colour, shape, position, assembly, cracks, scratches and other surface defects.

### 8.2. Intelligent defect detection

A deep learning system can learn to distinguish between compliant and defective products. The process can follow this sequence: Image capture → Pre-processing → AI model → Classification → Decision → Acceptance or rejection.


**Figure 5.** Quality control line assisted by vision and artificial intelligence.

### 8.3. Reducing human error

Fatigue, monotony and repetition can increase the risk of errors. A well-designed robotic system can maintain greater consistency in position, force, speed and trajectory. However, it remains essential to monitor errors relating to sensors, data, models or software.

### 8.4. Traceability

Robotic operations can be automatically logged: time, robot, product, batch, operation, decision, anomaly and human intervention. This traceability facilitates auditing and the identification of the source of any non-conformity.

## 9. Contribution to industrial safety

### 9.1. Handling hazardous tasks

Robotics can reduce workers' direct exposure to certain high-risk operations: high temperatures, hazardous substances, heavy loads, hard-to-reach areas, highly repetitive tasks and dangerous inspections.

### 9.2. Detection of hazardous situations

Using machine vision and sensors, an intelligent robot can detect the presence of a person, an obstacle, unusual movement, an insufficient safety distance or an anomaly in a trajectory.

### 9.3. Human-robot collaboration

Human-robot collaboration seeks to combine human capabilities — creativity, judgement, experience and adaptability — with robotic capabilities — precision, repeatability, strength, endurance and data collection.

**10. Safety requirements and standardisation**

The integration of robots into human environments requires strict standards. The ISO 10218-1:2025 and ISO 10218-2:2025 standards define safety requirements applicable to industrial robots and robotic applications or cells, respectively. The presence of AI never removes the obligation to carry out a formal risk analysis.

**11. Research methodology**

**11.1. Type of study**

This research adopts a descriptive, analytical and forward-looking approach. It is descriptive because it presents the technologies under study, analytical because it examines their relationship with industrial performance, and forward-looking because it deals with a technology that is still emerging.

**11.2. Literature review**

The literature review may draw on scientific articles, conference proceedings, international standards, industry reports and institutional publications sourced in particular from IEEE Xplore, Scopus, Web of Science, ScienceDirect, SpringerLink, the International Federation of Robotics and the European Commission.

**11.3. Study variables**

The independent variable is the level of integration between AI and humanoid robotics, measured in particular by autonomy, perception, accuracy, learning capacity, adaptability and human–robot collaboration. The dependent variables are productivity, quality and safety.

**Table 1.** Proposed dependent variables and performance indicators.

| Dimension | Possible indicators | Desired effect |
|---|---|---|
| Productivity | Units per hour; cycle time; availability; downtime; OEE | Increased output and reduced losses |
| Quality | Defect rate; rejection rate; detection accuracy; rework; first-pass yield | Reduction in non-conformities |
| Safety | Incidents; near misses; exposure to hazardous areas; ergonomic stresses | Reduction in human exposure to risk |

**12. Proposed conceptual model**

The proposed conceptual model links five main components: artificial intelligence technologies, humanoid robot capabilities, industrial applications, human–robot collaboration mechanisms and industrial performance indicators.

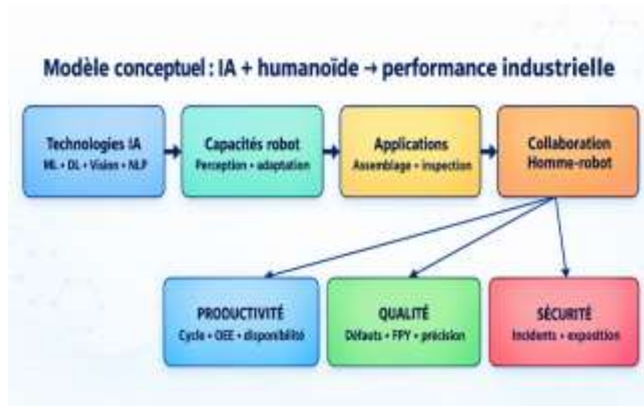


**Figure 6.** Proposed conceptual model of the contribution of AI and humanoid robotics to industrial performance.

**Artificial intelligence**: machine learning, deep learning, computer vision, natural language processing, intelligent planning.

**Robot capabilities**: perception, learning, navigation, manipulation, adaptation, human–machine interaction.

**Industrial applications**: assembly, material handling, inspection, maintenance, logistics, quality control.

**Performance**: productivity, quality and safety.

**13. Performance indicators**

- Productivity = Output / Resources used.
- Defect rate = (Number of defective products / Total number of products) × 100.
- Availability = (Actual operating time / Planned time) × 100.
- OEE = Availability × Performance × Quality.

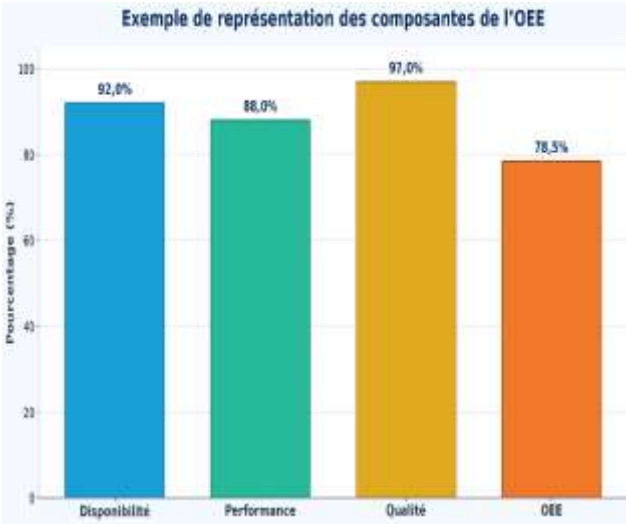


**Figure 7.** Illustrative example of the components of OEE; fictitious values.

An empirical study can compare the indicators before and after the integration of an AI-robotics solution in order to measure the actual effect of the system.

## 14. Expected results

- Reduction in certain cycle times.
- Automation of repetitive and arduous tasks.
- Increased flexibility of production systems.
- Improved detection of anomalies.
- Increased consistency of operations.
- Improved traceability.
- Reducing human exposure to certain hazardous tasks.
- Development of smarter collaboration between operators and machines.

These results should, however, be interpreted with caution: the documented benefits for industrial robots and cobots cannot automatically be generalised to all humanoid robots, the industrial adoption of which is still in its early stages.

**Table 2.** Summary of expected effects and verification indicators.

| Axis | Expected mechanism | Verification indicators |
|---|---|---|
| Productivity | Flexible automation, cycle optimisation, predictive maintenance | Cycle time, units per hour, availability, OEE |
| Quality | Automated inspection, AI vision, traceability | Defect rate, reject rate, FPY, accuracy |
| Safety | Substitution for hazardous tasks, presence/obstacle detection | Incidents, near misses, exposure |

## 15. Discussion

Recent research indicates that AI and intelligent robotics can enhance several aspects of industrial performance. Productivity can benefit from more flexible automation, quality from intelligent and continuous monitoring, and safety from a better distribution of tasks between humans and machines.

However, the success of these technologies does not depend solely on the performance of algorithms or mechanical capabilities. It also depends on human factors, organisation, training, cybersecurity, standardisation and worker acceptance.

The general relationship can be expressed conceptually as follows: Industrial performance = f (Technology, People, Organisation, Safety).

## 16. Limitations and challenges

### 16.1. Investment costs

The adoption of intelligent humanoid robots involves expenditure on acquisition, integration, IT infrastructure, sensors, software, maintenance and training. A cost-benefit analysis and a calculation of return on investment are required.

### 16.2. Technical complexity

A humanoid must combine perception, navigation, balance, manipulation, understanding of the environment, interaction and decision-making. A failure in one subsystem can affect the entire process.

### 16.3. Cyber security

A connected robot is also a computer system vulnerable to unauthorised access, parameter tampering, data interception, sensor tampering or certain attacks targeting AI models.

### 16.4. Reliability of artificial intelligence

The performance of an AI system depends on the quality of the data, the robustness of the model and its ability to generalise to industrial situations not encountered during training.

### 16.5. Acceptance by workers

Robotisation can give rise to fears of job displacement, mistrust or resistance to change. The success of a project therefore requires the involvement of workers and the development of new skills.

## 17. From industry 4.0 to industry 5.0

Industry 5.0 places greater emphasis on a human-centred, sustainable and resilient industry. This approach encourages us to view the humanoid robot not merely as a substitute for the operator, but as a technological partner that complements human capabilities.

The transition can thus be summarised as follows: Industry 4.0 = Human + Automation + Data + AI; Industry 5.0 = Human + Intelligent Robot + AI + Sustainability + Resilience.

## 18. Recommendations

Start with pilot projects focusing on clearly defined tasks.

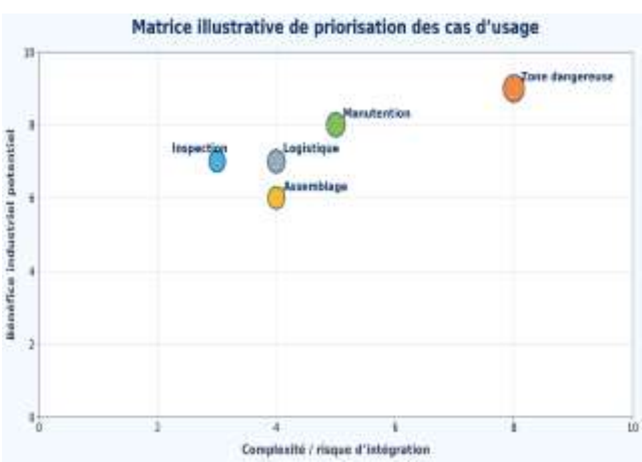


**Figure 8.** Illustrative matrix for prioritising humanoid use cases; conceptual positioning.

Prioritise repetitive, arduous or dangerous tasks.

Strengthen training for workers in AI, robotics, maintenance and cybersecurity.

Comply with applicable safety requirements, in particular ISO 10218-1:2025 and ISO 10218-2:2025.

Implement a cybersecurity strategy specific to connected robots.

Measure actual effectiveness using objective indicators such as OEE, cycle time, defect rate, availability, incidents and ROI.

Involve workers in the design of new workstations to promote effective human-robot collaboration.

## 19. Research outlook

- Multimodal models applied to humanoid robots.
- Reinforcement learning.
- Vision-language-action models.
- Robotic control via natural language.
- Digital twins of humanoid robots.
- Multi-robot systems.
- Explainable AI for robotics.
- Predictive maintenance of humanoids.
- Cybersecurity for autonomous robots.
- Human-robot trust.
- Socio-economic impact of robotisation.
- Deployment of humanoids in emerging economies.

## 20. Conclusion

The aim of this study was to analyse the contribution of artificial intelligence and humanoid robotics to improving productivity, quality and safety in Industry 4.0. The literature review shows that artificial intelligence is profoundly transforming the capabilities of robotic systems through machine learning, deep learning, computer vision, language models and planning systems.

In terms of productivity, these technologies can contribute to the automation of repetitive tasks, the optimisation of production cycles, predictive maintenance and flexibility. In terms of quality, they facilitate automated inspection, the detection of anomalies and traceability. With regard to safety, they offer the possibility of transferring certain hazardous tasks to machines and developing intelligent monitoring mechanisms.

It is, however, important to distinguish between the well-documented results for industrial and collaborative robots and those specifically relating to humanoids. The real challenge is therefore not simply to replace workers with robots, but to establish systems in which human and robotic capabilities complement one another.

Ultimately, artificial intelligence combined with humanoid robotics represents a significant prospect for the smart factory of the future. Its success will depend on striking a balance between technical performance, cost-effectiveness, safety, cybersecurity, human acceptance, professional skills and responsible governance.

**Table 3.** Summary of recent references cited in the article.

| Reference | Subject | Contribution to the article | Scope |
|---|---|---|---|
| Gao et al. (2024) | AI in manufacturing | State of the art and directions | AI / production |
| Cao et al. (2024) | Human-robot collaboration | Collaborative assembly and welding | Productivity / safety |
| Zhong et al. (2024) | Integrated safety and quality | Human-centred approach | Quality / safety |
| Dhanda et al. (2025) | HRC and Industry 5.0 | Opportunities and challenges | People / organisation |
| IFR (2025) | Industrial humanoids | Vision and level of maturity | Humanoid robotics |
| Yu et al. (2026) | Language models in robotics | Natural language control and planning | AI / Interaction |

## References


- Asif, S., Callari, T. C., Khan, F., Eimontaite, I., Hubbard, E.-M., Bahraini, M. S., Webb, P., & Lohse, N. (2026). Exploring tasks and challenges in human-robot collaborative systems: A review. Robotics and Computer-Integrated Manufacturing, 97, 103102.

- Cao, Y., Zhou, Q., Yuan, W., Ye, Q., Popa, D., & Zhang, Y. (2024). Human-robot collaborative assembly and welding: A review and analysis of the state of the art. Journal of Manufacturing Processes, 131, 1388–1403. https://doi.org/10.1016/j.jmapro.2024.09.044

- Dhanda, M., Rogers, B. A., Hall, S., Dekoninck, E., & Dhokia, V. (2025). Reviewing human-robot collaboration in manufacturing: Opportunities and challenges in the context of Industry 5.0. Robotics and Computer-Integrated Manufacturing, 93, 102937. https://doi.org/10.1016/j.rcim.2024.102937

- European Commission, Directorate-General for Research and Innovation. (2024). Industrial Technologies Roadmap on Human-Centric Research and Innovation for the manufacturing sector.

- European Commission. (2026). Industry 5.0. Directorate-General for Research and Innovation.

- Gao, R. X., Krüger, J., Merklein, M., Möhring, H.-C., & Váncza, J. (2024). Artificial Intelligence in manufacturing: State of the art, perspectives, and future directions. CIRP Annals, 73(2), 723–749. https://doi.org/10.1016/j.cirp.2024.04.101

- International Federation of Robotics. (2024). World Robotics 2024: Industrial Robots. IFR.

- International Organisation for Standardisation. (2025). ISO 10218-1:2025 — Robotics — Safety requirements — Part 1: Industrial robots. ISO.

- International Organisation for Standardisation. (2025). ISO 10218-2:2025 — Robotics — Safety requirements — Part 2: Industrial robot applications and robot cells. ISO.

- Kim, D. B., Bajestani, M. S., Lee, J. Y., Shin, S.-J., Kim, G.-Y., Sajadieh, S. M. M., & Noh, S. (2025). Human-in-the-loop in smart manufacturing (H-SM): A review and perspective. Journal of Manufacturing Systems, 82, 178–199.

- Yu, Z., Zhang, P., & Shi, J. (2026). Transformation of industrial robotics with natural language models: Recent progress and future prospects. Robotics and Computer-Integrated Manufacturing, 97, 103113. https://doi.org/10.1016/j.rcim.2025.103113

- Zhang, C., Xu, Q., Yu, Y., Zhou, G., Zeng, K., Chang, F., & Ding, K. (2025). A survey on the potential, pathways and challenges of large language models in next-generation intelligent manufacturing.

Robotics and Computer-Integrated Manufacturing, 92, 102883. https://doi.org/10.1016/j.rcim.2024.102883

- Zhong, Y., Karthikeyan, A., Pagilla, P., Mehta, R. K., & Bukkapatnam, S. T. S. (2024). Human-centric integrated safety and quality assurance in collaborative robotic manufacturing systems. CIRP Annals, 73(1), 345–348. https://doi.org/10.1016/j.cirp.2024.04.008