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# The Path From Industry 4.0 To Industry 5.0: Analysis Of New Trends In Safety Management

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**Abstract**

The emergence of Industry 5.0, defined by the integration of machine and human capabilities in smart factories, represents a significant leap in the development of manufacturing and industrial processes. It presents further dangers and difficulties concerning security and safety. A thorough review of the important concerns about security and safety in Industry 5.0 is given in this article. Safety is explored in various aspects, emphasising the dynamic nature of human-machine collaboration and the requirement for cutting-edge safety procedures and technology to guarantee employees' well-being. In order to provide a safer workplace, the authors investigate the combination of wearable technology, machine learning, and real-time monitoring. The increasing connection and data interchange between devices focuses on security issues in Industry 5.0 based on cloud-based systems, IoT devices, and the possibility of cyberattacks as weaknesses. This paper also emphasises how crucial it is to approach the interaction between safety and security in Industry 5.0 from a holistic standpoint. To develop a culture of safety and security in smart factories, it promotes thorough risk assessments, the creation of industry standards, and continual training and awareness initiatives. To sum up, Industry 5.0 has enormous potential for advancement and expansion, but it also calls for closer attention to security and safety. This article promotes a sustainable and safe future for the sector by being a useful resource for researchers, industry experts, and policymakers attempting to traverse the complex terrain of Industry 5.0.

*Keywords*: safety, security, safety 5.0, industry 5.0, industry 4.0, digital industry, smart factory, workers' safety

## 1. Introduction

The manufacturing paradigm has changed so drastically over the past several years that it has been dubbed "the fourth industrial revolution." This revolution, which is still outpacing the digital revolution, began in Hannover, Germany, in the 21st century. But we might call this era of the Fourth Industrial Revolution "The Age of Digital Objects" if we consider that all machines and systems in this era operate using digital objects, which are composed entirely of integers (0 and 1). During the 18th and 19th centuries, the industry was mechanised by steam-powered machinery and new production processes, which encouraged capital accumulation. An industry revolution is the term for periodic modifications from that era. The transition from an agrarian economy to an industrial one was essentially brought about by the First Industrial Revolution, which began in the United Kingdom. The second stage of this fundamental revolution began with the construction of factories that used electricity to carry out mass production. In the late 1960s, industrial processes saw the adaptation of information and communication technology (ICT) systems, facilitating manufacturing automation (Fargnoli, 2020). This revolution is in its fourth stage, but a fifth is coming. Through the use of software and new technologies like artificial intelligence (AI), the Internet of Things (IoT), and full-scale robotics of self-driving and unmanned vehicles, mechanical processes were accelerated during this revolution, which resulted in a dramatic decrease in the contribution of humans while increasing production speed by performing extremely large calculations. The evolution of hardware, software, and the Internet opened the way for producing responsive, communicative, and interoperable things. The terms "4th

revolution," "Industry 4.0," "smart manufacturing," "digital industry," "intelligent factory," and "advanced manufacturing" have all been used to describe this transformation.
Industry 4.0, in reality, is the automation and digitalization of industrial settings together with the concurrent creation of a digital supply chain supporting goods, their associated business context, order selection, delivery, retail, and even potential consumers (Hsu, 2022): The fourth industrial revolution, or "Industry 4.0," is a new wave of technologically driven industrial production that aims to completely transform the manufacturing process. Its foundations include the emergence of new mobile internet technologies, the Internet's increased speed and adaptability, and the development of equipment that connects to this worldwide network to enable the production of intelligent industrial robots. Unmanned aerial vehicles, intelligent readers (sensors), robots, and other gadgets that we may classify as parts of each part and communicate with online (Di Nardo, 2020)
As technology advances, there is a parallel recognition of the critical importance of safety within these dynamic industrial ecosystems. Safety 4.0 emerges as a natural extension of Industry 4.0, emphasizing the integration of advanced safety measures into smart manufacturing environments. Safety 4.0 leverages real-time data, predictive analytics, and AI-driven systems to proactively identify and mitigate potential hazards, ensuring a safer working environment for personnel and safeguarding the integrity of operations.
Looking beyond the current horizon, the concept of Industry 5.0 envisions a future where humans and machines collaborate synergistically, emphasizing human-centric approaches to manufacturing. This transition brings forth Safety 5.0, representing an evolution in safety protocols that align with the cooperative interplay between human workers and intelligent machines. Safety 5.0 places a premium on human well-being, emphasizing the need for ethical AI, continuous training, and a holistic safety culture that fosters trust and collaboration between humans and automated systems.

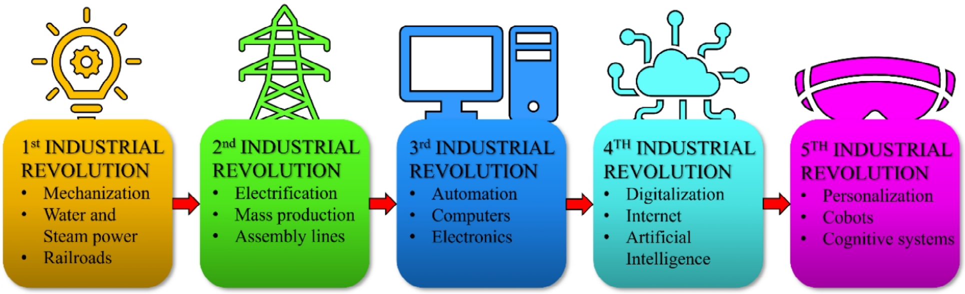


Fig. 1. The various stages of the Industrial Revolution.

In this narrative, we explore the trajectory from Industry 4.0 to Industry 5.0, delving into the intricacies of Safety 4.0 and Safety 5.0. These paradigms redefine the way industries operate and underscore the pivotal role of safety in shaping the future of work, where technological advancements and human welfare harmoniously coexist.
The ability to successfully complete a mission in various situations is becoming the new definition of safety. This corresponds with the shift in the EU's definition of Industry 5.0 from categorising safety as the just non-existence of damage to positive support of system resilience. Safety and effective system performance cannot be viewed as mutually exclusive problems from a human-centric standpoint. An inadequate comprehension of cognitive ergonomics and human factors can lead to underperformance of personnel and systems, erroneous decision-making, and, ultimately, psychological distress among staff members. Therefore, improving our functional understanding of new socio-technical interactions and applying it to new human-centric techniques might benefit efficiency and safety.
In the relentless pursuit of technological innovation and industrial advancement, the landscape of workplace safety has undergone a transformative journey. From the early emphasis on compliance and risk mitigation, the evolution has led us to the era of Safety 5.0. This paradigm encapsulates a profound shift in the approach to occupational well-being. Safety 5.0 represents a visionary stride towards a future where the synergy between human workers and intelligent technologies takes centre stage, fostering a workplace culture that prioritizes human-centric values alongside technological efficiency.
As we embark on this exploration of Safety 5.0, it is crucial to understand its roots in the broader context of industrial revolutions. Safety 5.0, however, extends beyond the realms of advanced technologies and automation. It heralds a new era where the relationship between humans and machines becomes collaborative rather than merely cooperative. The emphasis shifts from risk reduction to the holistic well-being of the workforce, recognizing that a safe and productive workplace is one where technology augments human capabilities while maintaining a profound respect for the unique qualities and insights humans bring. This exploration into safety 5.0 delves into the multifaceted dimensions of this emerging paradigm, exploring its principles, applications, and the profound impact on reshaping occupational safety. In a world where the convergence of humans and intelligent

technologies is inevitable, Safety 5.0 serves as a beacon guiding us towards a future where safety is not just a regulatory requirement but a fundamental aspect woven into the fabric of every technological advancement, ensuring a harmonious coexistence of innovation and human welfare.
Building on the developments of Industry 4.0, Industry 5.0 will prioritise creating cutting-edge machine learning and artificial intelligence technologies. Because of this, producers can automate increasingly intricate procedures, which will help them cut expenses further and boost the effectiveness of resilient appliances.

### 1.1. Need for the study

With "The Age of Digital Objects" comes the need to push the boundaries and respond quickly while retaining high stability. For this reason, this study focuses on function as a reference for developing adaptive abilities and overcoming difficult situations. The following research questions, which will be used as input for the literature review, were developed after a bibliographic study was conducted, in which several papers were evaluated and then combined with the most pertinent keywords chosen:
RQ1: What are the innovations in Safety brought by the fourth industrial revolution?
RQ2: What are the new advantages in the digital industry?
RQ3: What function does safety play in the human-robot interface of Digital Industry?
RQ4: What are the foundational elements of the digital industry in safety, and how are they evolving in Industry 5.0?
The authors performed a systematic literature review and followed a review protocol of published articles and reviews. This literature review on the selected keywords in the digital age will synthesise existing knowledge, identify gaps and provide useful information for researchers, practitioners and policy-makers. The article follows a descriptive review approach, and the paper's overall structure is shown in Fig. 2.

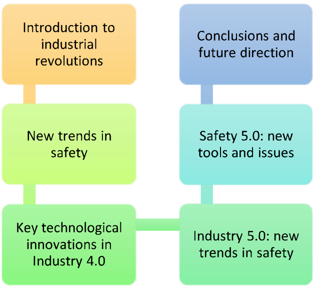


Fig. 2. The structure of the article.

### 1.2. Methodology and structure

The Scopus database searched for and selected relevant articles excluding conference papers. We carried out a systematic review; the framework adopted is illustrated in Figure 2, which shows that the study began with the research of Industry 4.0 technologies. Further, the main topics that have been addressed are safety in 4.0, the path to industry 5.0 and the innovations brought in the safety world. The central part of the survey presents the answers to the research question proposed. Finally, conclusions from the study, implications of the study, and future research direction were derived. It should be emphasised that the research is limited to covering the most recent and significant advancements made in the field, summarising and giving readers an overview of the current state and future directions of the field rather than including every paper published on the subject.

## 2. Thematic Analysis

### 2.1 Artificial intelligence

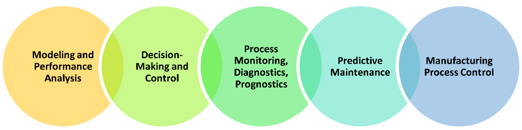


Fig. 3. Opportunities of AI in a manufacturing system.

Artificial Intelligence (AI) stands at the forefront of technological innovation, reshaping how we perceive and interact with the world. Rooted in creating machines that can simulate human intelligence, AI encompasses various applications ranging from problem-solving and language understanding to visual perception and decision-making. As a multidisciplinary field, AI draws upon computer science, mathematics, neuroscience, and engineering, converging to develop systems capable of learning from data, adapting to dynamic environments, and performing tasks that traditionally required human intelligence. The rapid advancements in AI technology have fuelled transformative changes in industries such as healthcare, finance, and transportation but have also ignited ethical debates and societal discussions about the potential implications of creating machines with cognitive abilities. As we delve deeper into the age of artificial intelligence, understanding its capabilities, limitations, and ethical considerations becomes imperative for navigating the evolving landscape of this groundbreaking field.

Predictive maintenance, predictive analytics, inventory management, machine vision, industrial robots, and supply chain management have all shown significant promise for using AI in Industry 4.0 (Padmakumar, 2022). Liu et al.'s evaluation (Ruonan, 2018) of using different AI-driven algorithms, including k-NN, Naive Bayes, ANN, and Deep Learning, in rotating equipment fault diagnosis reduced maintenance costs, eliminated safety hazards, and decreased machine downtime. Since every algorithm has its own advantages and disadvantages in terms of precision, speed, and resilience, they suggest creating a hybrid intelligent system to deal with upcoming difficulties. Recurrent neural networks (RNNs)-based algorithms have been employed by Zhao et al. (Zhao, 2018) as a predictive maintenance tool to track the machine's health. The approach has been successfully deployed to diagnose gearbox and bearing faults as well as tool wear in milling operations. In order to establish a precise correlation between the quantity of material removed and the different operational parameters employed in a polishing process, Wang et al. used Deep Belief Network (DBN), a data-driven approach (Wang, 2017).

An interesting application of Artificial Intelligence in the smart factories are personal protective equipments (PPE). Employee security has improved due to developments in occupational health and safety made possible by information and communication technologies (ICTs). Because the equipment can make judgements based on environmental parameters, using Personal Protective Equipment based on ICTs lowers the likelihood of accidents at work. Generating PPE models and creating devices with increasingly complex features like monitoring, environment sensing, and danger identification are made feasible by paradigms like the Industrial Internet of Things (IIoT) and Artificial Intelligence (AI). This study describes a prototype smart helmet that assesses threats in almost real-time while keeping an eye on the surroundings for its users. A platform powered by AI receives the sensors' data and starts the analysis. Research on AI's potential uses in the industrial sector has also been done recently. The article's system architecture allows for the analysis of intelligent manufacturing by fusing technology and communication systems. The material supplied gives a general idea of the potential uses of AI across all industrial sectors. AI enables decision-making to be optimised in both straightforward and intricate scenarios. Numerous AI applications have been developed in a wide range of fields as a result of the AI boom that has occurred in recent decades. Currently, there are progressively improved ways to safeguard employees' lives while they are in high-risk situations. Because of this, artificial intelligence (AI) and security measures are used in industry to build environments that provide better circumstances for industry development. The suggested device aims to enhance occupational health and safety (OHS) by lowering the likelihood of illness, injury, absence, or death and improving employee performance. Implementing intelligent technologies for early danger identification in the workplace is another goal in order to support the third wave. This research aims to develop a novel helmet that can sense various parameters, including air quality, luminosity, force exerted between the user's head and the helmet, temperature, humidity, and atmospheric pressure. By using specialised IoT modules, this helmet will enable a work team to respond to accidents more quickly. This data is used to set independent alarms. Similarly, the sensor data are transformed to be classified in a Convolutional Neural Network, which outperforms three other supervised learning models in cross-validation with an accuracy of 92.05%. Many injuries may be prevented with a helmet, and in the event of an accident, worker damage is reduced by early diagnosis or attention. (Campero-Jurado, 2020)

### 2.2. Machine learning

Machine learning, a subset of artificial intelligence, has emerged as a pivotal technology with transformative potential in enhancing industry safety. By leveraging algorithms that enable systems to learn and improve from experience, machine learning contributes significantly to risk mitigation and accident prevention. In manufacturing, construction, and transportation industries, where safety is paramount, machine learning algorithms analyse vast datasets to identify patterns and anomalies that may indicate potential hazards. Predictive maintenance models, a key application of machine learning, enable companies to anticipate equipment failures and schedule maintenance proactively, reducing the likelihood of accidents caused by malfunctioning machinery. Additionally, machine learning algorithms can be employed to analyse real-time data from sensors and devices, allowing for the swift detection of safety deviations and the immediate implementation of corrective measures. As industries increasingly embrace machine learning, the synergy between technology and safety measures fosters a proactive approach to risk management. It underscores the potential to create safer working environments for employees. The integration of machine learning in Industry 4.0 enhances operational efficiency and establishes a dynamic safety framework that adapts to evolving challenges, ultimately fostering a secure and resilient industrial landscape. Using algorithms, ML enables data flow between linked systems and automatically enhances the process. A conventional automated factory may become a smart factory thanks to the unparalleled performance of the iterative learning and optimisation cycle. ML is used in the industrial sector for various purposes, including supply chain management, predictive maintenance, health monitoring of structures, condition monitoring of machines, and predictive quality control (Padmakumar, 2022). Machine learning algorithms are used to interpret the data gathered from several sensors to identify failure patterns and even forecast future failures, potentially doing away with the need for frequent physical inspections. Real-time monitoring and the automatic detection of faulty parts may be achieved without the need for human involvement by fusing machine vision and machine learning algorithms. Because unsold inventory or a lack thereof affects the manufacturer, forecasting customer behaviour and supply chain management are two more business areas that have a greater influence on profitability. Inventory control and demand forecasting have benefited from applying machine learning methods.

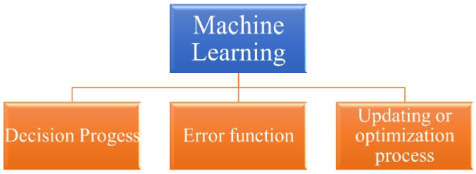


Fig. 4. Machine learning key points.

### 2.3. Cybersecurity

Cybersecurity has emerged as a critical element of risk management and operational resilience in the industrial landscape. The potential vulnerabilities to cyber attacks increase considerably as companies embrace digital transformation, integrate smart technology, and use networked systems. These days, harmful actors looking to exploit weaknesses and interfere with operations primarily target manufacturing plants, energy facilities, and other vital infrastructure. In the industrial sector, the ramifications of a triumphant cyberattack beyond mere data breaches encompass tangible harm, production interruptions, and even public safety hazards (Babeshko, 2023).
Strong cybersecurity defences are essential for industrial control system security and the protection of sensitive data. This means putting in place safe network topologies, regularly patching and upgrading systems, and encouraging staff members to be aware of cybersecurity issues. The future resilience of the industrial sector depends on the proactive integration of cybersecurity methods to reduce risks and guarantee the uninterrupted operation of critical processes. Certain threat categories that are frequently targeted at certain industries include ransomware, insider assaults, server access, credential theft, remote access trojans, spam, web scripts, and misconfiguration. Figure 4 lists the eight primary, generally recognised cybersecurity domains that help prevent information theft. Several authorities have released documentation and recommendations in recent years to help industry manage cybersecurity-related challenges in their practices. According to a recent survey, companies hit by cyberattacks have either had to shut down production lines, lose a significant amount of man-hours, suffer significant financial losses, or all of the above. In addition to monetary losses, it may result in client mistrust, a damaged reputation, and possibly legal action. According to research, businesses have a lot of opportunity to use digital technology on factory floors. However, they must also be aware of the growing cyberthreats and create and fund appropriate data security-safety programmes.

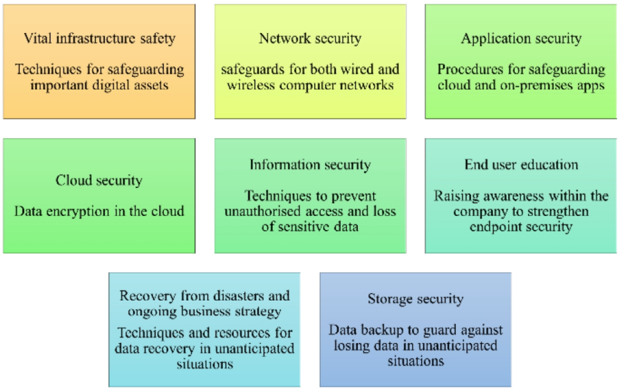


Fig. 5. Various cybersecurity domains.

### 2.4. Internet of things

The Internet of Things (IoT) refers to a network of interconnected physical devices, vehicles, appliances, and other objects embedded with sensors, software, and network connectivity, allowing them to collect and exchange data. The primary goal of IoT is to enable these devices to communicate with each other and with centralized systems, creating a seamless and intelligent environment where data can be gathered, analysed, and utilized to enhance efficiency, productivity, and functionality across various domains such as home automation, healthcare, industrial processes, and more. Integrating IoT technologies facilitates the automation of tasks, real-time monitoring, and the generation of insights, leading to more informed decision-making and improved overall system performance. Thanks to the affordable and small-sized Internet of Things (IoT) sensors, more physical items might be connected, improving the system's functionality and safety (Devarshi Shah, 2020). Heat, temperature, pressure, humidity, vibration, friction, and movement are just some of the sensors whose data are gathered in real-time in a production system to establish a statistical correlation with the product's performance. The potential of IoT in future smart factories is vast, ranging from helping with preventative maintenance and creating a safer work environment. By suitable sensors, the Internet of Things (IoT) system may also be used in hazardous work settings including chemical factories, nuclear power plants, wastewater treatment facilities, and manufacturing sectors to gather vital machine data that can be used to monitor and regulate production and operation. But as more "things" are linked, safeguarding sensitive data becomes increasingly difficult and requires new safety algorithms (Riel, 2017).

### 2.5. Cyber physical system

Industry 4.0 is increasingly developing cyber-physical systems that innovate industrial engineering and traditional control systems with the deployment of advanced technological paradigms such as IoT, machine learning and artificial, big data to make factories more efficient and with greater manufacturing innovation with a higher degree of self-awareness and self-configuration. An intelligent computer system that incorporates sensing, processing, control, and networking features into tangible things and links them to the Internet and one another is known as a cyber-physical system. Despite their striking similarities, IoT and CPS vary in one important way. A device that is integrated with vital sensors (sensing) and can collect and transfer data (networking) over the Internet is referred to as an Internet of Things (IoT). On the other hand, a CPS includes parts necessary for computing and control that make the system extremely efficient, in addition to the sensors and Internet. CPSs are subject to additional safety and security risks, on top of the usual ones with any internet-connected equipment (Peng, 2013). These problems include malware, data corruption, and threats to privacy and confidentiality.
There is a push towards the cloud for all applications requiring high raw computing power to improve all engineering applications that reach real-time execution with high reliability, such as minimising communication errors (O'Donovan, 2019). In order to help complex industrial plants achieve their objectives of being resilient, sustainable, and human-centric, cyber-physical human-centricity (CPHS) been developed (Fraga-Lamas, 2022). It enhances operator safety and traceability in industrial processes dependent on collaborative robots and massive machinery. In order to make better use of available resources and avoid mishaps or accidents involving these machines, the suggested use case centres on a manufacturing floor where human proximity sensing is employed to identify whether a machine should or shouldn't be running. By moving from dangerous on-site, in-vehicle work

to remote, computer-assisted piloting, which may also make the job more interesting to younger generations, the challenges of having an elderly crew can also be lessened. utilising contemporary telepresence methods and remote control via augmented reality (AR) and virtual reality (VR). For safety reasons, those operating the robot or participating in a collaborative application need to go through a learning and training process. The competent and efficient control of robots and their safety in industrial environments form the basis of intelligent automation. Safety and security issues include unpredictability in system failure, complex socio-technical systems, human-machine interactions, cyber-physical attacks, unsecured remote configuration, a lack of standards, and resilience (El-Kady, 2023). The environmental and economic sustainability effects are additional significant factors (Balasubramanian, 2021). Despite being pioneers in the research of the impact of automation on safety, professionals in process safety and environmental protection will face new challenges and opportunities due to Industry 4.0. In a broader sense, though, it may be believed that everyone interested in the matter—business, the environment, and the community—is responsible for safeguarding the environment (Gobbo, 2018).

## 3. Industry 5.0

As we stand on the brink of the next phase in industrial evolution, Industry 5.0 emerges as a transformative paradigm, ushering in a new era characterized by the harmonious collaboration between humans and advanced technologies. Building upon the foundations of Industry 4.0, which witnessed the integration of digital technologies in manufacturing processes, Industry 5.0 seeks to redefine the relationship between humans and machines. Unlike its predecessor that emphasized automation and data exchange, Industry 5.0 places a renewed focus on the human touch, acknowledging the indispensable role of human expertise, creativity, and intuition in conjunction with intelligent technologies. In the context of Industry 5.0, the convergence of cutting-edge technologies such as artificial intelligence, robotics, and the Internet of Things takes a unique turn, aiming not to replace human labour but to augment and empower it. The paradigm envisions a future where humans and machines collaborate symbiotically, each contributing distinctive strengths to create a more agile, adaptable, and resilient industrial landscape. As we embark on this journey into Industry 5.0, it becomes imperative to explore the implications, challenges, and opportunities arising from this novel industrialisation approach.

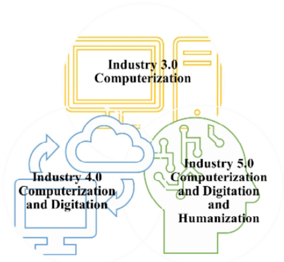


Fig. 6. The key differential factors of Industry 3.0 Vs 4.0 Vs 5.0.

### 3.1. Safety 5.0

Safety has always been a cornerstone of any well-functioning society, and the evolution of safety practices is integral to our ongoing commitment to protecting lives and preserving well-being. In recent years, the concept of Safety 5.0 has emerged as a potential paradigm shift, reflecting a holistic and dynamic approach to ensuring the welfare of individuals in various environments, especially in the workplace. Safety 5.0 represents a departure from traditional safety models by incorporating cutting-edge technologies, innovative methodologies, and a profound understanding of human factors. At its core, Safety 5.0 emphasizes the need for a comprehensive and adaptive safety culture that not only prevents accidents but also actively enhances individuals' overall well-being and productivity. One of the key tenets of Safety 5.0 is the integration of advanced technologies into safety frameworks. This involves using artificial intelligence, sensor networks, and real-time data analytics to predict and prevent potential hazards. Smart safety systems can now identify patterns, analyse data from various sources, and provide proactive measures to mitigate risks before they escalate. The human element is central to Safety 5.0, acknowledging that individuals play a pivotal role in maintaining a safe environment. This paradigm encourages a culture of empowerment and engagement, where employees are not merely recipients of safety protocols but active contributors to the safety ecosystem. Training programs, communication channels, and feedback mechanisms are optimized to ensure that everyone in the organization feels a sense of responsibility for their safety and the safety of their colleagues. Adaptability and flexibility are also hallmarks of Safety 5.0. Recognizing the

ever-changing nature of workplaces and the emergence of new risks, this paradigm encourages continuous improvement and the ability to adapt safety measures to evolving circumstances. Integrating real-time monitoring, feedback loops, and regular reassessment of safety protocols ensures that organizations can avoid potential challenges.
Furthermore, Safety 5.0 places a strong emphasis on psychological and mental well-being. Beyond physical safety, this paradigm recognizes the importance of addressing stress, fatigue, and other factors impacting an individual's mental health. Creating a work environment that fosters psychological safety contributes not only to the prevention of accidents but also to the overall satisfaction and productivity of employees. In conclusion, Safety 5.0 represents a visionary approach to safety that aligns with the complexities of our modern world. By combining technological advancements, a focus on human factors, adaptability, and a holistic understanding of well-being, Safety 5.0 endeavours to create environments where individuals work safely and thrive. As we navigate the future, the principles of Safety 5.0 serve as a guiding light, reminding us that safety is not merely a set of rules but a dynamic and integral part of our collective journey towards a secure and fulfilling existence.

### 3.1. Human robot relationship

There are tasks for which typical robotic systems are not appropriate. An optimal co-working combination between people and robots may be accomplished depending on the necessary balance between the cognitive understanding that only humans can contribute and the speed, stamina, and physical strength that robots have to provide (Marinelli, 2022). This combination, known as human–robot cooperation (HRC), aims to maximise each contributor's unique skills (Castro, 2021). Vicentini et al. (Vicentini, 2021) define collaborative robotics as an umbrella word that expresses the basic notion that human-machine contact transcends simple space delimitation (or material flows or sequences) and produces a productive job. Moreover, cobots eliminate the need for extra safety precautions common with industrial robots by working directly and concurrently in the same area as human operators. Recent developments in manufacturing technology, referred to as Industry 5.0, aim to build Smart Factories with more automated production lines and supply networks. Here, the fifth Industrial Revolution's core concept is integrating state-of-the-art technologies into employment settings and commercial procedures, necessitating paradigm shifts that significantly affect both people and technology. Adopting technological innovation is advantageous for businesses since it ensures significant benefits, including expenses, technology, management, etc.
Additionally, it allows employers to enhance employee safety (Bertoncel, 2019). New methods, cutting-edge technology, various workplace configurations, societal or management changes, and the notion that "new scientific understanding permits a long-standing problem to be classified as a risk" are all significant contributors to the emergence of new hazards. One example is the risk to working conditions created by new tools that require state-of-the-art safety evaluation methodologies. As per the expert prognosis on Named Entity Recognition (NER) by the EU Agency for Safety and Health at Work (Adriaensen, 2019), workers encounter increased mental and emotional strain because of the complexity of novel knowledge, the need to modify work methods, and inadequately designed human-machine boundaries.Nevertheless, this significant advancement does not entirely eliminate the need for human operators; rather, it calls for their involvement in a hybrid task execution process in conjunction with robots. Ensuring human operators are safe is critical for future factories when humans and robots share close quarters and work side by side. Because human conduct is ambiguous, collaborative apps are highly risky regarding real operation execution. Presently, certain novel technologies possess the ability to convert the non-formal and objective depiction of a human-robot collaboration application into a logic model, considering numerous crucial aspects of teamwork, including work cell configurations, robot kinematics, operator attributes, interactions between robots and operators during tasks, and the associated risk assessments. Therefore, creating a model that considers people as more than simply an operational component and mimics their error-prone behaviour is crucial for a comprehensive safety assessment. Focusing, in particular, on formal models that reproduce the most common human errors that can occur during manufacturing tasks is crucial because it allows for identifying (and correcting) dangerous scenarios that could be missed if a purely functional model of humans is applied (Askarpour, 2019). Usually placed in communal areas, collaborative robots are tested in a range of ways to see how well they function and how well they meet human safety standards for robotic systems that can lower the likelihood of pertinent minor injuries (Dede, 2021). It is crucial to investigate automated standard compliance to ensure the parties are safe for separate components to function together. Standard compliance is created using predetermined security and safety norms, from which measurable indicator points are derived. These illustrate the level of compliance by representing system configurations recommended by relevant security, safety, or process management standards and recommendations (Bicaku, 2019).

### 3.3. Smart sensors and augmented reality

At the heart of the transformative paradigm of Industry 5.0 is the integration of smart sensors, sophisticated devices designed to capture, process, and communicate data in real-time. In the context of Industry 5.0, these smart sensors play a crucial role in reshaping safety practices within industrial environments. As industries embrace the principles of Industry 5.0, deploying smart sensors emerges as a linchpin in achieving heightened efficiency, productivity, and, notably, a new safety standard. These sensors, equipped with advanced capabilities such as IoT connectivity, artificial intelligence, and edge computing, transcend the limitations of traditional safety mechanisms. Rather than merely reacting to incidents, smart sensors enable a proactive and predictive safety approach that is integral to the fabric of Industry 5.0. Smart sensors continuously monitor the industrial environment, detecting anomalies and potential hazards in real time. Whether it's identifying unusual temperatures, gas leaks, or equipment malfunctions, these sensors provide an instantaneous response to mitigate risks before they escalate.

Through predictive analytics, smart sensors assess the condition of machinery and equipment, predicting when maintenance is needed. This prevents unexpected breakdowns and enhances overall safety by ensuring that all equipment operates within optimal parameters. Smart sensors equipped with motion and occupancy detection capabilities contribute to ensuring the safety of personnel within industrial settings. By tracking the movement of individuals, these sensors can alert to potential collisions, unauthorized access to restricted areas, or emergencies, fostering a safer working environment. Monitoring environmental factors, such as air quality, temperature, and humidity, is crucial for ensuring the well-being of workers. Smart sensors provide a comprehensive overview of the workplace environment, allowing for timely interventions in adverse conditions that could impact health and safety. In an emergency, smart sensors are pivotal in triggering rapid and targeted responses. From automatic shut-off mechanisms in case of a gas leak to activating emergency lighting systems, these sensors enhance the speed and precision of emergency protocols. The integration of smart sensors with wearable devices enhances personal safety. Wearables equipped with sensors can monitor vital signs, detect fatigue, and provide real-time alerts to individuals, ensuring that workers are protected from external hazards and internal health risks. As Industry 5.0 unfolds, the applications of smart sensors for safety are poised to redefine occupational health standards. By fostering a dynamic and interconnected safety ecosystem, these sensors empower industries to not only meet regulatory requirements but exceed them, creating environments where the well-being of individuals is paramount in the pursuit of operational excellence.

Functional safety is crucial for providing sufficient human and machine protection in this dispersed, dynamic, and highly linked environment (Morato, 2023). The implementation of distributed and adaptable functional safety systems is made possible by the growing availability of wireless networks. However, because of their inherent uncertainty, these networks are known to introduce undesired delays, which can reduce safety performance.

## 4. Conclusions

Industry 4.0 emphasized automation and data-driven processes, setting a digital revolution in motion. In contrast, Industry 5.0 emphasizes human-machine collaboration, merging technology with human ingenuity for a holistic approach to industrial progress. Similarly, Safety 4.0 leveraged digital tools for proactive risk mitigation, but Safety 5.0 goes further by prioritizing human-centric safety. This shift recognizes the irreplaceable role of human intuition and well-being in industrial environments, moving beyond mere compliance to create a culture where safety is everyone's responsibility. As industries transition to Safety 5.0, research is suggested on the ethical implications of autonomous safety systems, the economic impact of this transition, and the psychosocial effects on employees.

In conclusion, we recommend some research propositions for future articles that could analyse some critical aspects of new trends in the safety of smart 5.0 industries:

*RP1:* How autonomous safety systems can bring ethical implications deploying autonomous safety systems, considering issues related to decision-making, accountability, and transparency, to develop guidelines for responsible AI use in Safety 5.0

*RP2:* What is the economic impact of Safety 5.0 adoption: an evaluation of the economic implications of adopting Safety 5.0 could be analysed, considering factors such as initial investment costs, productivity gains, and long-term financial benefits to provide insights into the economic feasibility of transitioning to advanced safety technologies.

RP3: Are there psychosocial implications of Safety 5.0 implementation? Investigating this issue could be measured considering factors such as employee stress, job satisfaction, and the perception of autonomy, as organizations increasingly rely on technology for safety management.

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