RESEARCH REPORT

Eurofound

Anticipating and managing the impact of change

Human–robot interaction: What changes in the workplace?

Human–robot interaction: What changes in the workplace?

European Foundation
for the Improvement of
Living and Working
Conditions

When citing this report, please use the following wording:
Eurofound (2024), *Human–robot interaction: What changes in the workplace?* Publications Office of the European Union, Luxembourg.

Authors: Sara Riso and Dragos Adascalitei (Eurofound)

Research manager: Sara Riso (Eurofound)

Research project: The impact of new developments in human–machine interaction on work organisation and working conditions (220501)

Providers: The second and third chapters of this report are based on case studies commissioned by Eurofound from the VVA–Open Evidence consortium. One case study – on a warehouse in Italy – was commissioned from Open Evidence separately by the European Commission's Joint Research Centre and the International Labour Organization as part of research on algorithmic management. The case study was reused for this report because aspects of human–robot interaction were explored during the fieldwork, following a similar interview protocol to that used for the other case studies and including questions related to human–robot interaction.

Acknowledgements: Eurofound would like to thank colleagues from the European Agency for Safety and Health at Work: Ioannis Anyfantis, for reviewing this report and contributing to Chapters 2 and 3; and Maurizio Curtarelli, for providing data from the agency's 2022 OSH Pulse survey. Gratitude is also extended to Ignacio González Vázquez and Enrique Fernández-Macías (of the Joint Research Centre), who made available a case study for this research and facilitated synergies between their research on algorithmic management and Eurofound's research on human–robot interaction.

Luxembourg: Publications Office of the European Union, 2024

Print:	ISBN 978-92-897-2410-4	doi:10.2806/67956	TJ-09-24-447-EN-C
PDF:	ISBN 978-92-897-2409-8	doi:10.2806/601796	TJ-09-24-447-EN-N

This report and any associated materials are available online at https://eurofound.link/ef23010

Research carried out prior to the UK's withdrawal from the European Union on 31 January 2020, and published subsequently, may include data relating to the 28 EU Member States. Following this date, research only takes into account the 27 EU Member States (EU28 minus the UK), unless specified otherwise.

The European Foundation for the Improvement of Living and Working Conditions (Eurofound) is a tripartite European Union Agency established in 1975. Its role is to provide knowledge in the area of social, employment and work-related policies according to Regulation (EU) 2019/127.

European Foundation for the Improvement of Living and Working Conditions

Telephone: (+353 1) 204 31 00
Email: information@eurofound.europa.eu
Web: https://www.eurofound.europa.eu

Contents

Executive summary

Introduction

Advanced robotic systems and applications disrupt workplaces; they transform the way work is carried out, often resulting in changes to business models and redefining roles, tasks and methods of work. Artificial intelligence (AI) has played a pivotal role in enhancing these systems, giving them greater capabilities, functionalities and flexibility than more conventional robots. AI has also facilitated seamless collaboration and interaction between humans and robots in various industries. This is most prominently illustrated by collaborative robotic applications, through which AI enables closer worker–robot interaction in shared workspaces.

As advanced robots become more complex and prevalent in modern work environments, understanding how workers and robots interact and the implications for work organisation and working conditions is crucial for robots' successful integration into the workplace. The changes brought about by autonomous or semi-autonomous advanced robotics require thoughtful consideration and proactive management to ensure a positive impact on businesses and workers.

Drawing on survey data and case studies investigating advanced robotic systems and applications for task automation, this report contributes to the policy debate on work automation, highlighting new forms of interaction between workers and robots and the changes to work organisation and working conditions that they entail.

Policy context

Unlike conventional robots, usually confined to cages and positioned at a safe distance from humans, advanced robots equipped with sensors and enhanced functionalities ensure greater safety when in proximity to humans. They enable closer human–robot interaction and collaboration characterised by shared goals and more synchronised tasks. Despite these benefits, the forms of interaction arising from the use of increasingly advanced robotic systems, especially those with embedded AI capabilities, may pose new policy and regulatory challenges. The notion of human centricity is more relevant than ever in ensuring safe and effective human–robot interaction.

As part of the EU's digital strategy, several policy initiatives on AI have emphasised a human-centric approach to technology development and use. In the context of advanced robotics, this involves ensuring that systems are designed and deployed in a manner that respects human values and fundamental rights. Furthermore, the European Commission has taken steps to address liability and accountability issues arising from AI use, proposing a revised product liability directive and an AI civil liability directive.

Safety is another important concern in human–robot interaction; with the EU's adoption in 2023 of the new European Machinery Regulation (Regulation (EU) 2023/1230), it sought to update the safety requirements for machinery (and related products) on the EU market. This regulation acknowledges that safety risks extend beyond physical damage to psychological stress. However, the primary legal instrument governing matters of occupational safety and health (OSH) remains the OSH Framework Directive (89/391/EEC).

Other key challenges arising from interaction with advanced robots relate to skills requirements. For some time, the EU has recognised the impact of technological advancements on the labour market and the skills the workforce requires. In this regard, a major policy initiative is the European Skills Agenda for sustainable competitiveness, social fairness and resilience. The agenda encompasses several actions focusing on upskilling and reskilling to ensure individuals have the skills necessary for current and future job markets.

Key findings

- The adoption of robotic technologies is influenced by external and internal factors. According to data gathered by the Eurostat survey on information and communications technology use in enterprises, high labour costs and difficulties in recruiting personnel feature prominently as reasons to invest in robots. Increased competitiveness and productivity gains are key internal factors.
- Industrial and service robots are most prevalent among large enterprises. In 2022, approximately 1 in 5 large EU companies used industrial robots (used for welding, laser cutting, etc.), whereas only 1 in 10 used service robots (used for surveillance, transport, etc.). The adoption rate among small and medium-sized enterprises is notably lower, primarily due to the significant capital investment required to implement robotic technologies and the economies of scale required to fully leverage the resulting efficiency gains.

- When assessing the risks associated with human–robot interactions, establishments tend to focus on physical safety but overlook the psychosocial implications. Involving workers more in the design and deployment of robotic technologies could help reduce certain stressors, particularly uncertainties emerging in the initial stages of technology adoption. Worker involvement is often necessary to adapt or customise systems or applications for the operational environment.
- When integrating robotic solutions into the workplace, as well as emphasising safe technology use, change management programmes can help resolve uncertainties, increase workers' resilience in the face of change and enable them to adapt to new work routines. In most establishments, working with advanced equipment did not require specific qualifications or certifications. Nonetheless, adopting robotic systems required new digital, analytical and soft skills in some establishments in certain sectors (e.g. manufacturing) or certain occupations (e.g. managers and supervisors).
- While data from a European Agency for Safety and Health at Work survey suggest that human–robot interaction is associated with increased work intensity, increased surveillance, deterioration of the social environment and reduced autonomy, evidence from case studies suggests that the negative outcomes stem from organisational factors and management choices, rather than the technology itself.

Policy pointers

- Robotic technologies, particularly when AI-powered, promise to boost productivity, increase workplace safety, alleviate task monotony, reduce physical strain and make work more engaging and rewarding. However, realising these advantages necessitates treating workers as co-creators of technological solutions, rather than merely costs to be minimised. Policy actions are essential to promote human-centric design, including awareness-raising campaigns, public incentives for research and development with a focus on human centricity, and the development of guidelines for ethical and human-centric design.
- The social partners can play a crucial role in shaping policies that prioritise human-centric values and involve participatory approaches to technology design and implementation in workplaces. The European social partners' 2020 framework agreement on digitalisation is an important instrument for coordinating efforts and promoting human centricity in relation to robotics.
- Continued efforts should be directed towards supporting training initiatives that prioritise the development of skills relevant to human–robot collaboration, including digital literacy and adaptability and resilience in the face of automation. It is equally essential to ensure the effective implementation of principle 10 of the European Pillar of Social Rights (on health and safety) and the EU strategic framework on OSH.

Introduction

Policy context and scope of the report

Modern work environments are being increasingly transformed by the application of advanced robotic technologies in production processes and service delivery. Artificial intelligence (AI) has revolutionised the field of advanced robotics and has brought the capabilities of robotic applications to a new level of complexity and sophistication. The new wave of advanced robots – equipped with both physical and cognitive functionalities – entails much closer interaction with workers than more conventional robotic applications. Despite the many benefits, continued and closer human–robot interaction has implications for quality of work. Such implications include increased cognitive load (or workers' loss of control over their own job), expanded monitoring and surveillance capabilities, adaptation to new and changing roles, and the emergence of new psychological and safety risks (EU-OSHA, 2018; Eurofound, 2023a). Previous research by the European Agency for Safety and Health at Work (EU-OSHA) identified three key dimensions relevant to occupational safety and health (OSH) – physical, psychosocial and organisational – along with various associated effects (EU-OSHA, 2022a).

There is increasing recognition among policymakers of the need to strike a balance between fostering innovation and increasing productivity and efficiency on the one hand and safeguarding quality of work on the other hand. Recent policy developments at EU level highlight the importance for EU policymakers and legislators of addressing some of the most pressing challenges to the responsible and human-centric deployment and use of advanced technology systems. A major EU regulatory initiative is the AI Act; preliminary political agreement on the act was reached on 9 December 2023 (European Commission, undated-a). Following a risk-based approach, the AI Act sets out legal regulations to ensure that AI systems brought into the EU market are safe and human-centric and respect people's fundamental rights and the values of the EU, as enshrined in the Charter of Fundamental Rights of the European Union.[1] A complementary regulatory instrument to the AI Act is the General Data Protection Regulation (GDPR). While the AI Act regulates AI as a product and is applicable to developers and providers of AI systems, the GDPR protects individuals' data protection rights in line with a set of principles that are ethical at their core (Eurofound, 2023a).[2] Although the use of digital technologies is not explicitly mentioned in the legislation, the GDPR is of crucial importance in the context of advanced robotics systems interacting closely with humans and inevitably capturing 'human data' (data about workers and their work activities) either directly or indirectly.

When it comes to increasingly autonomous systems, accountability and liability are also key concerns. According to an EU-wide enterprise survey conducted in 2020, liability issues in connection with AI systems are a top concern for European enterprises and are regarded as an important obstacle to AI adoption (European Commission, 2020a). To respond to such concerns, the European Commission proposed a new AI liability directive and a revision of the Product Liability Directive in 2022 (European Commission, 2022a, 2022b). The European Data Protection Supervisor examined the two legislative proposals in an opinion issued on 11 October 2023 (No. 42/2023) and recommended broadening the scope of the regulations concerning civil liability in the context of AI systems, by giving equal consideration to damages that may be caused by both high-risk and non-high-risk AI systems.

Furthermore, the new Machinery Regulation, adopted in 2023 – applicable from 20 January 2027 and replacing the Machinery Directive (Directive 2006/42/EC) – seeks to address new safety challenges posed by new digital technologies, particularly in the field of AI and advanced robotics. Robotic systems with embedded AI capabilities fall under the definition of 'machinery' and are therefore subject to health and safety requirements and relevant conformity assessment procedures. The new regulation acknowledges that safety risks are not only limited to physical damage but also include psychological stress that may result from interacting with the machines.[3]

1 The AI Act classifies AI systems into different groups depending on the level of risk they pose, from minimal-risk to high-risk and even banned AI systems. High-risk AI systems in the employment context are those deployed for work management and recruitment, and hence subject to scrutiny, checks and conformity assessments. This risk-based approach helps to avoid preventing uses of AI that pose little risk and allows some flexibility.

2 The seven data protection principles in the GDPR are (1) lawfulness, fairness and transparency; (2) purpose limitation; (3) data minimisation; (4) accuracy; (5) storage limitation; (6) integrity and confidentiality (security); and (7) accountability.

3 Safety in human–machine interaction is also addressed by several international standards and specifications to ensure the safe operation of emerging technologies in different contexts. ISO 10218-1:2011 and ISO 10218-2:2011 are the international robot safety standards. Their applications have expanded to new types of advanced robots, such as collaborative robots (ISO/TS 15066:2016) and personal care robots (ISO 13482:2014).

More specifically in the area of OSH, the OSH Framework Directive (89/391/EEC) sets out general principles, objectives and obligations aimed at safeguarding workers' health and safety. It provides a framework within which employers must assess and manage risks to ensure the well-being of their workers. The main instruments for managing OSH are risk assessments in the workplace. The obligations for employers include risk assessment, prevention measures, training, information provision, and workers' consultation in health and safety matters.

Aligning with principle 10 of the European Pillar of Social Rights (on health and safety), the new EU strategic framework on OSH for 2021–2027 underscores the importance of anticipating and managing change in the new and increasingly digital world of work, putting a renewed emphasis on the need to tackle risks to psychosocial well-being. In a resolution of 10 March 2022, the European Parliament turned the spotlight on new OSH challenges arising from the increased digitalisation of work. While recognising that 'AI and digitalisation plausibly facilitate human-machine synergies', the European Parliament's resolution stresses the importance of introducing 'safeguards against the adverse impacts of algorithmic management[4] on the health and safety of workers' and draws attention to 'OSH concerns such as the emergence of new forms of monitoring and management of workers based on the collection of large amounts of real-time data that can lead to legal, regulatory and ethical questions' (European Parliament, 2022).

Psychosocial risks emerge not only when workers are subject to new forms of work monitoring as part of their close interaction with robots or machines, but also when they lack the skills required to carry out the new or changed tasks assigned to them or they face skills obsolescence and job loss. Previous research draws attention to the potential risk of robotic systems leading to the deskilling of the workforce. This occurs as workers no longer complete entire tasks, resulting in a diminished understanding of the complete process (EU-OSHA, 2022a). However, the available empirical evidence of technology design resulting in deskilling is ambiguous and contradictory (Barrett et al, 2012).

These are legitimate concerns that warrant responses from policymakers. The importance of supporting workers in transitioning to new jobs and adapting to new roles is clearly stated in the first principle of the European Pillar of Social Rights: 'Everyone has the right to quality and inclusive education, training and life-long learning in order to maintain and acquire skills that enable them to participate fully in society and manage successfully transitions in the labour market'. Several policy initiatives put this principle into practice and set out concrete policy actions in the area of skills; the European Commission (undated-b) offers an overview of initiatives under the first principle of the European Pillar of Social Rights. A prominent initiative in this regard is the European Skills Agenda for sustainable competitiveness, social fairness and resilience (European Commission, 2020b). This initiative renews the EU's commitment to addressing gaps in digital skills, strengthening vocational education and training, and providing opportunities for upskilling and reskilling to respond to changing skills needs. Furthermore, the Recovery and Resilience Facility is expected to further boost EU Member States' investments in upskilling and reskilling initiatives. The 2024 European Commission Communication on boosting startups and innovation in trustworthy artificial intelligence reiterates its commitment to enhancing talent and nurturing the necessary skills in key technology application domains, including robotics, as part of the Digital Europe Programme (European Commission, 2024).

Against this multifaceted and evolving background, this report aims to provide insights from both survey data and explorative case studies on challenges and opportunities arising from new forms of human–robot interaction in European workplaces. The objective is to inform policy debates on job quality in connection with the use of advanced robotic systems and applications for the automation of physical tasks that entail close interaction between humans and robots.

Key definitions

Digitalisation, digitisation and automation

This report builds on Eurofound's conceptual framework on the digital age, in which 'digitalisation' is a broad term used to describe the increasingly widespread adoption and use of digital technologies, with transformative effects on work, employment and society more generally (Eurofound, 2018a). Key driving forces – or vectors of change – behind this digital transformation are the automation of work and digitisation of processes. In Eurofound's conceptual framework, automation refers to 'the replacement [in full or in part] of labour input by machine input for some types of tasks in production and distribution processes', whereas the digitisation of processes is defined as 'the use of sensors and rendering devices to translate (parts of) the physical production process into digital information (and vice versa)'. In practice, the

4 The International Labour Organization defines algorithmic management as the use of computer-programmed procedures to coordinate labour input in an organisation (Baiocco et al, 2022).

distinction between the two vectors of change is not clear cut, as they co-exist in many applications both in manufacturing and in the services sector. Keeping in mind this overlap, this report focuses mainly on automation, given its strong focus on advanced robotic systems.

The International Organization for Standardization (ISO) defines a robot as an 'actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks' (ISO 8373:2012). Other defining features are a control system and an interface with that control system, which allow human operators to manage their application. This definition does not explicitly distinguish between robots and advanced robots. The literature often discusses advanced robotics in terms of advancements in robots or newer generations of robots within the wider context of robotic installations rather than as a separate category (Eurofound, 2019a). In this sense, the more technologically advanced Industry 4.0 robots are defined by the incorporation of additional features.[5] In contrast to traditional robotic devices, advanced robots can execute tasks requiring higher degrees of dexterity, flexibility and accuracy (see Table 1). They can therefore deal with less structured applications and can be applied in a greater variety of environments.

AI applications and sensor technologies enable robots to acquire new competencies, such as machine vision, speech recognition and force (touch) sensing (Tantawi et al, 2019; Bulgheroni et al, 2021). AI may, for example, be integrated into a physical robot structure, enabling autonomous navigation without requiring continuous human intervention. AI can also enhance robotic tactile sensing capabilities. This allows robots to 'feel' and respond to different levels of force or pressure, making it possible for them to handle fragile materials, for example in laboratory settings. This may be achieved by integrating sensors and AI algorithms for interpreting touch feedback. General-purpose AI – with its ability to execute a diverse range of tasks, including generating various forms of new content (termed 'generative AI') – has the potential to further enhance human–robot interaction.

Table 1: Examples of advanced robots

Examples of advanced robotic applications	Description
Autonomous mobile robots (AMRs) and advanced guided vehicles (AGVs)	AMRs and AGVs are specific forms of automated and interconnected cyber-physical systems. Both AMRs and AGVs are examples of robotic systems that combine physical components with computational elements, creating a synergy between the cyber (computational) and physical (mechanical) aspects of the system. The e-commerce and logistics sectors were early adopters of AMRs and AGVs. Automotive manufacturing facilities also employ AGVs extensively to facilitate efficient material movement along assembly lines. In addition, AMRs and AGVs are used in healthcare settings to automate tasks such as medication delivery, logistics and inventory management in hospitals and clinics.
Collaborative robots (cobots)	Collaborative robots, often referred to as 'cobots', are robotic applications designed to work alongside humans in a shared workspace or in close proximity to humans. Unlike traditional industrial robots, which operate separately from humans, cobots interact directly with workers, enhancing their capabilities and increasing productivity. They are equipped with advanced safety features and sensing technologies to ensure safe human–robot interaction. Cobots have various uses across industries. In manufacturing, they can assist in tasks such as assembly, packaging and quality control. Cobots can work collaboratively with workers on production lines, increasing the efficiency and accuracy with which tasks are completed. Cobots also have applications in healthcare, where they can assist in patient care, sterilisation processes and laboratory tasks, reducing the workload of healthcare professionals and improving patient outcomes.
Social robots	Unlike industrial robots, which are used primarily for automation in manufacturing, social robots are autonomous robots designed to interact and communicate with humans socially. They are equipped with sensors, actuators and advanced AI algorithms, enabling them to perceive their environment, process information and respond to human cues and commands.

Sources: *Eurofound, 2018b, 2019a*

5 The term 'Industry 4.0' has its roots in manufacturing and industrial processes, specifically referring to the fourth industrial revolution. This revolution is characterised by the integration of digital technologies, advanced automation, data exchange and smart systems into various aspects of manufacturing and industry. The term is also increasingly used to describe broader transformations that extend beyond manufacturing and into the services sector. In this report, the term 'Industry 4.0' is used with this broader interpretation.

Human–machine interaction versus human–robot interaction

Advanced robotics often involves sophisticated systems that are capable of complex task completion, autonomous decision-making and interaction in dynamic environments. Human–machine interaction plays a crucial role in facilitating seamless communication and collaboration between humans and advanced robotic systems. It is, however, important to differentiate between the terms ‘human–machine interaction’ and ‘human–robot interaction’. While ‘human–machine interaction’ refers to interaction between humans and any type of machine or computer system, the term ‘human–robot interaction’ relates more specifically to interaction between humans and robots, which is the main focus of this report. Unlike machines in general, robots are physical entities capable of movement and manipulation, and human–robot interaction often involves – to a varying extent depending on the robot’s level of sophistication – collaboration or cooperation with humans on a set of tasks.

Drawing on a taxonomy developed by Onnasch and Roesler (2021), EU-OSHA classifies human–robot interaction in three categories: co-existence, cooperation and collaboration (EU-OSHA, 2022b; Heinold et al, 2023). Co-existence refers to occasional encounters between humans and robots where interaction is brief and confined in time and space. This interaction lacks a shared goal, and the actions of the participants are not synchronised. For instance, a transport robot passing by a supervisor in a warehouse exemplifies co-existence. Cooperation and collaboration involve closer interaction between humans and robots, characterised by a common goal and synchronised tasks. Cooperation entails both humans and robots working towards a shared objective, with pre-defined task divisions. They each handle distinct subtasks leading to the final outcome. Collaboration represents the most closely intertwined form of interaction, where humans and robots work simultaneously on the same object or task. For instance, when assisting in lifting patients, a collaborative interaction occurs. In such cases, both the human and the robot work together to achieve a common goal necessitating immediate coordination. Subtasks are continuously assigned and, if necessary, adjusted to suit the specific situation. The case studies conducted as part of the research summarised in this report explore robotic applications involving a certain degree of cooperation and collaboration with workers.

An important concept in human–robot interaction is that of ‘human factors’. The term refers to the various aspects of the design, implementation and operation of robots that consider human capabilities, limitations, preferences and well-being. The integration of human factors into the design of advanced robotic systems and applications, particularly in manufacturing settings, is gaining in importance considering the closer interaction between humans and robots that these advanced robotic systems and applications entail (Fletcher and Webb, 2017). When robots were still separated from humans, human factors and human-centred design were not as important.

Organisational human factors also play an important part in the successful implementation of industrial human–robot interaction (Charalambous et al, 2015; EU-OSHA, 2022a). These include the effective communication of changes, employee involvement, the presence of a process champion (who understands the technology and benefits and can motivate others to embrace the change), the provision of training and workforce development, the facilitation of organisational flexibility through employee empowerment, and the commitment and support of senior management (Charalambous et al, 2015). These aspects were considered in the investigation of the case studies as part of the approach to technology adoption in each establishment.

Methodology

Statistical analysis and main data sources

The quantitative analysis in this report draws on two datasets.

The first is the Community survey on information and communications technology usage and e-commerce in enterprises. The source dataset is publicly available from Eurostat [isoc_e]. Since 2018, the survey has included a module that is conducted every two years on the use of robots and 3D printers. The survey distinguishes between industrial and service robots (see Chapter 1 for definitions and examples), and allows for an assessment of the prevalence of robots in EU enterprises by country, size of enterprise and sector of activity. Importantly, the unit of analysis is the enterprise and not the specific application itself. This sets the Eurostat dataset apart from other commonly used international sources of data on robot prevalence. These include the International Federation of Robotics dataset, which provides data at the level of technology and therefore includes data on robot installations. When necessary, data from the Eurostat survey and the International Federation of Robotics are combined to draw conclusions about the prevalence of robots in Europe and recent market trends.

The second data source is EU-OSHA's OSH Pulse survey, which is a representative telephone survey focusing on the impact of the COVID-19 pandemic on a range of worker-level outcomes (EU-OSHA, 2022c). Fielded in spring 2022, the survey is based on a representative sample of about 27,000 workers across all EU Member States. The survey was also fielded in Iceland and Norway. However, these countries are excluded from the analysis presented in this report.

The OSH Pulse survey asked respondents which digital technologies they use in their main job. One of the possible responses to the question was 'robots that interact with you', which is the main explanatory variable used in the analysis presented in Chapter 1. While the sample is sufficiently large for statistical analyses, it does not allow for disaggregation between countries for the items that are the focus of this report. Importantly, only around 3% of the respondents to the survey reported that they use robots that interact with humans. Therefore, the analysis is maintained at a high level of aggregation that allows conclusions to be drawn without resulting in low sample sizes.

EU-OSHA's OSH Pulse survey is used in a regression analysis that focuses on the association between working conditions and the use of robots that interact with humans. The survey was implemented as a Flash Eurobarometer survey aiming to provide insights into workers' health and well-being in the context of existing and emerging OSH risks. As all outcomes used in regressions are dichotomous variables, the analysis uses logistic regression models with country fixed effects. For ease of interpretation, the regression results are summarised visually using average marginal effects.

Case study research

This report draws on seven multistakeholder case studies of selected establishments from various sectors and countries in the EU. The fieldwork was carried out between December 2022 and April 2023 through semi-structured interviews with respondents across all establishments and relevant stakeholder groups (see Table 2). Each case study consisted of interviews with management representatives in different functions (including innovation and human resources (HR)), line managers and worker representatives (works councils or trade unions), and focus groups with employees in different occupations. The case studies conducted were informed by 30 one-to-one interviews and 7 focus groups with workers. This multistakeholder approach was intended to provide a balanced account of how advancements in robotic technologies have changed human–robot interaction and their effects on work organisation and working conditions.

The interviews were conducted on the establishments' premises in accordance with a semi-structured interview guide (for each type of stakeholder interviewed). The interviews were organised around a set of core themes relevant to human–robot interaction in the context of the adoption of advanced robotic technologies in different work settings. Preliminary desk research on human–robot and human–machine interaction and aspects of job quality in the context of automation was conducted to inform the content of the interview guide. The analysis of the interviews was complemented by field visits to the establishments and desk research.

Table 2: Number of interviews and types of interviewees across the selected establishments

Role of interviewee	Number of respondents
Innovation manager/technology provider	7
HR manager	7
Line manager	9
Worker representative	7
Worker (interviewed in a focus group)	31
Total	**61**

Source: *Case study reports*

An adapted version of the job quality framework developed by Eurofound (2013, 2017) was used to guide the review of and to structure the findings from the case studies. This framework – which is based on European Working Conditions Survey (EWCS) data – incorporates many elements or characteristics of jobs that workers consider necessary for 'good work'. These include the intrinsic quality of work (skills, autonomy and social support), working time (duration, scheduling, flexibility and intensity), health and safety (physical and psychosocial risks) and employment quality (career prospects and earnings). Ensuring good job quality is crucial for creating a work environment where human–robot interaction not only is efficient but also promotes the well-being and satisfaction of workers. This, in turn, leads to better performance, adaptability and collaboration in the evolving workplace.

While conducting case studies is a valuable method for the in-depth exploration of real-world phenomena, it comes with inherent challenges and potential biases that necessitate careful consideration. The first major challenge concerned the recruitment of establishments for the case study research. When exploring new phenomena – and more so the use of digital technologies and their impact on job quality – companies are generally concerned about giving away their competitive advantages or trade secrets, exposing their weaknesses or, even worse, attracting negative publicity if they participate in such research. The reluctance among the establishments identified to participate in the research also extended the time required to identify eligible cases.

The establishments that ultimately agreed to participate in the research were those eager to share their positive experiences and provide a different (more positive) narrative from the prevailing one of robotic technologies being a threat to jobs. This may have introduced self-selection (and therefore a positive bias) in the findings.

Access to workers through senior management or a public relations department may have introduced another layer of bias in the study. They may have strategically chosen participants to present the deployment of technology in a favourable light. Furthermore, the individual case study reports – on which Chapters 2 and 3 are based – were subject to validation and approval by interviewees before they were used for this report. It is also crucial to acknowledge that the findings concerning the impact of technology adoption in the selected establishments, including the effects on productivity and wages, should be interpreted in a short-term context; the case studies are all based on the relatively recent implementation of robots, and long-term changes cannot be ruled out.

Despite the above-mentioned caveats, the collection of case studies provides a valuable insight into the extent to which advanced robotic systems – involving a higher level of human–robot interaction than more conventional robots – change ways of working and affect working conditions. Moreover, they allow important lessons to be learned for the implementation of more human-centric applications in the workplace. The analysis of the case studies also relies on the researchers' direct observations during field visits, providing a better understanding of how the technologies were integrated into work processes, the functionalities of the technologies and the nature of the human–robot interaction involved.

Table 3 presents an overview of the cases investigated, detailing the main characteristics relevant to the research. All establishments selected for this research were required to be situated in a Member State of the EU (although not necessarily headquartered in the EU) and to have some form of formal worker representation. Other criteria that guided the selection of cases are listed below.

- At least one of the technologies classified as advanced robotics or a combination of technologies involving significant human–robot interaction (in the form of cooperation or collaboration) had to be adopted.
- The technology had to be embedded in a sufficient number of work-related processes and affect a sizeable share of the workforce in the establishment.
- The operational maturity of the technologies under investigation had to be beyond the piloting or experimental stage when the fieldwork was carried out, to enable the impact of the human–robot interaction required by the technology to be detected. This requirement limited the cases that could be selected to more prevalent or common use cases. Cutting-edge robotic applications identified during desk research that were in an experimental or piloting phase were therefore not investigated further.

It should also be borne in mind that the case studies are exploratory in nature and are by no means representative of other establishments of the same size or operating in the same sectors. The research employed an opportunistic sampling technique to select cases, aiming to capture diverse approaches to the design, adoption and implementation of robotic technologies in the workplace, with a specific emphasis on human–robot interaction. The case studies should also be viewed not as best practices but rather as illustrative of common approaches and showcasing both strengths and weaknesses, enabling valuable lessons to be gleaned from each one.

Furthermore, the robotic technologies investigated vary in their degree of sophistication and complexity. The establishments implementing the most advanced robotic systems followed an incremental approach to automation, implementing automation technologies gradually and in stages, rather than adopting comprehensive or large-scale automation systems all at once. In such complex systems, AI technologies are often integrated into hardware and control systems, adding an extra layer to existing production processes, with the aim of optimising efficiency. This integration makes it challenging – particularly for external observers – to identify AI components without having a detailed knowledge of a system's architecture.

In addition to the case studies conducted for this research, the report draws on desk research. Where appropriate, it also draws on findings from previous case studies on automation carried out by Eurofound and EU-OSHA, in which significant aspects of human–robot interaction were examined.

Table 3: Main characteristics of the case studies investigated

Establishment (country)	Establishment size (number of employees)	Ownership structure	Form of employee representation	Technology in focus	Type of human–robot interaction
Warehouse (France)	63	Limited company	Works council	Mobile shelving robot	Cooperation
Manufacturing plant (Lithuania)	536	Subsidiary of a group (a traded stock company)	Works council	Advanced robotics system for production, assembly and packaging	Collaboration
Warehouse (Italy)*	1,021	Private for-profit organisation with shareholders	Appointed worker representative	Mobile shelving robot	Cooperation
Cleaning company (Spain)	110	Subsidiary of a large group	Trade union	Autonomous cleaning cobots	Cooperation
Hospital (Italy)	958	Public hospital	Trade union	Advanced robotic system for drug preparation and distribution	Cooperation
Hospital laboratory (Sweden)	120	Public hospital	Trade union	Cobots for handling test samples	Collaboration
Restaurant (Sweden)	45–50	Owned by the local authority	Trade union	Social robots	Cooperation

Note: * *The case study on the warehouse in Italy was investigated as part of International Labour Organization and Joint Research Centre research on algorithmic management (ILO and JRC, 2024). It also explored aspects of human–robot interaction and followed a similar interview protocol to the one used in the other case studies covered in this research. Specific questions on human–robot interaction were covered in the interviews.*
Source: *Eurofound research, 2022–2023*

Report structure

This report investigates the impact of advanced robotics on all aspects of work and the implications of human–robot interaction in the workplace.

Chapter 1 draws on two main data sources: Eurostat's community survey on information and communications technology use in enterprises and EU-OSHA's 2022 OSH Pulse survey. Although the focus of the OSH Pulse survey is on occupational safety and health, it includes questions pertaining to working conditions that relate to the use of robots interacting with workers. This chapter reports on issues that are also investigated from a qualitative perspective in the case studies. These include time pressure and work overload, the quality of the social environment, autonomy and control over work pace in the context of the use of robots that interact with workers.

Chapter 2 introduces prevalent and emerging use cases of advanced robotics, encompassing varying degrees of human–robot interaction, across diverse sectors. Special attention is given to the case studies conducted specifically for this report, which are explored in detail in boxes. This chapter also delves into aspects of human–robot interaction in the context of technology adoption, examining its role in the case studies investigated.

Chapter 3 draws on both desk research and case studies on automation, investigating the impacts of human–robot interaction on various dimensions of work organisation and working conditions.

Chapter 4 provides conclusions and policy pointers derived from the data analysis and information collected from the case studies.

1 Prevalence of robots and impacts on working conditions

Prevalence of advanced robots in the EU

This chapter analyses the use of robots in the EU, using data published by Eurostat to gauge the prevalence of robot use across countries and sectors. The analysis also focuses on the main purposes for which robots are used and the key reasons for which companies opt to invest in automation technologies. While the focus of this report is on robots that can interact with humans, the descriptive analysis that follows casts a broader net, focusing more generally on industrial and service robots (see Box 1). The vast majority of industrial robots do not have the capacity to interact with humans; rather, they can perform physical tasks and manipulate objects in a standardised way without having advanced capabilities for interaction.[6] However, the definition of service robots highlights that a degree of interaction with humans may be required for their operation. The focus on industrial and service robots in this chapter is driven by data limitations, as available aggregate statistics at EU level do not allow the disaggregation of data beyond this rudimentary distinction.

Figure 1 presents the share of enterprises in the EU using industrial and service robots between 2018 and 2022. The first finding worth noting is that in many countries the share of enterprises using robots remained relatively stable. In the absence of large shocks, the share of companies using robots cannot vary significantly across short periods, given that investment in robotic installations requires relatively large initial capital investments. At EU level, the share of enterprises using robots experienced a slight decline between 2018 and 2022, from 6.7% to 6.3%. The EU-level trend is driven by a moderate decline in the share of enterprises using robots in several countries, including Bulgaria, Finland, the Netherlands, Poland and Spain. In contrast, in Denmark, Estonia, Lithuania and Malta, the share of enterprises using robots increased substantially between 2018 and 2022. However, it is important to note that these countries have relatively small economies and markets for robots, which can contribute to the overestimation of relative changes.

Box 1: Distinction between industrial and service robots

In its questionnaire, Eurostat distinguished between industrial and service robots using the following definitions.

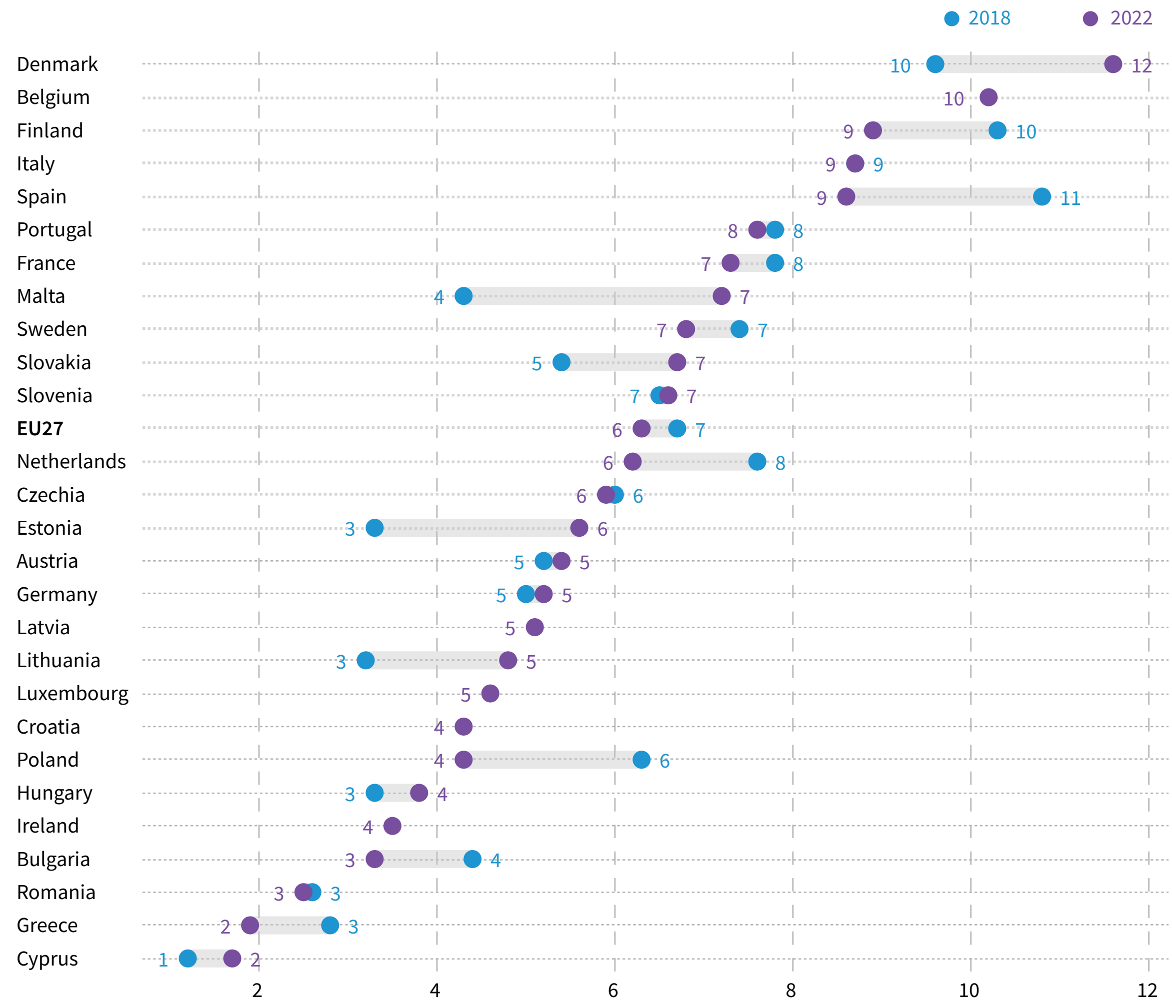
An **industrial robot** (e.g. robots used for welding, laser cutting or spray painting) is an automatically controlled, reprogrammable, multipurpose manipulator programmable on three or more axes. It may be either fixed in place or mobile. Most industrial robots comprise a robotic arm and a series of links and joints, with an end effector that carries out the task.

A **service robot** (e.g. robots used for surveillance, cleaning or transport) has a degree of autonomy and can operate in complex and dynamic environments. It may require interaction with people, objects or other devices. Service robots use wheels or legs to achieve mobility and are often used in inspection, transport or maintenance tasks.

The distinction between the two types of robots is therefore driven by the level of autonomy that they have in performing tasks: whereas industrial robots perform tasks in a structured environment with external safeguards, service robots have a degree of autonomy, which allows them to operate in human environments. As a result, they require greater sensing, motion and decision-making capabilities and are designed to perform specific tasks (Eurostat, 2023).

6 Data published by the International Federation of Robotics demonstrate that in 2023 fewer than 10% of robotic installations around the world were collaborative robots or robots that were designed to interact directly with humans (IFR, 2023).

Figure 1: Share of enterprises using industrial or service robots in the EU, 2018–2022 (%)



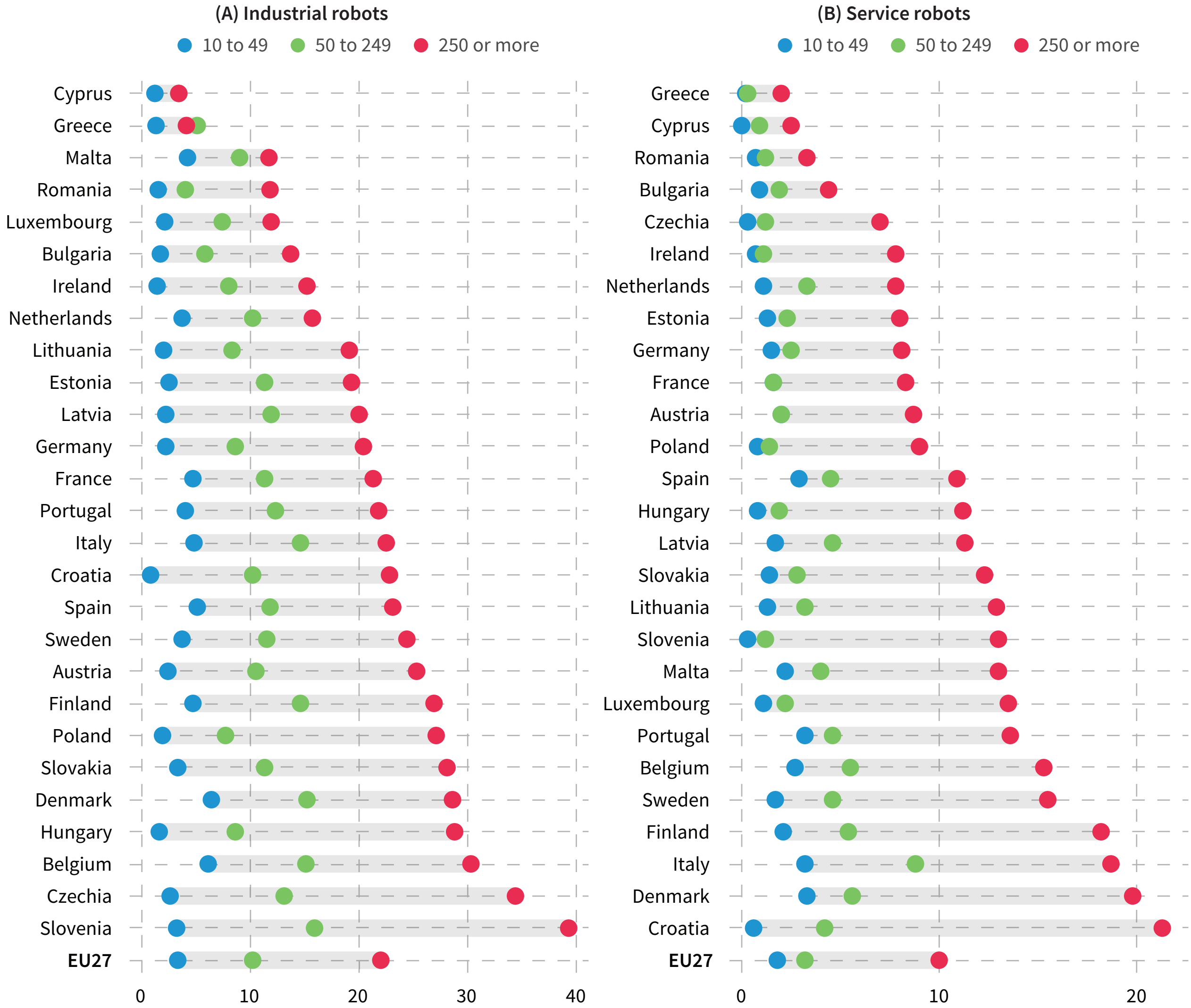
Notes: *No data available for 2018 for Belgium, Croatia, Ireland, Latvia and Luxembourg.*
Source: *Eurostat [isoc_eb_p3d]*

Data suggest a trend towards the increasing concentration of the EU's robot market.

Although the share of enterprises in the EU using robots declined slightly between 2018 and 2022, the number of robot installations increased during the same period (IFR, 2023). Europe continues to hold its position as the second-largest market for industrial robotic installations globally. Amid labour supply challenges stemming from demographic ageing, demand, especially for service robots, is expected to increase (IFR, 2023). Large national markets for robots, such as those of France, Germany, Italy, Poland and Spain, have seen substantial increases in the number of robots in recent years. This indicates a tendency in the market for robots in Europe to become more concentrated, with a lower or relatively stable share of companies using robots but a higher number of robots per company.

The use of industrial and service robots is correlated with company size. As Figure 2 shows, in all Member States (except Greece in the case of industrial robots), larger companies are more likely than smaller ones to use both types of robots, with wide variation across countries in terms of prevalence. More than 1 in 3 large companies in Czechia and Slovenia use industrial robots, while the same is true for fewer than 5% of large companies in Cyprus and Greece. Furthermore, on average, around 1 in 5 large companies in the EU use industrial robots and only 1 in 10 use service robots. The large intra-EU geographical variation in the use of industrial and service robots is driven by the sectoral composition of national economies. Countries with large, complex manufacturing sectors, such as automotive, petrochemical and metal industries, tend to have a higher share of enterprises using industrial robots.

Figure 2: Share of enterprises using industrial (A) and service (B) robots, by size of enterprise, 2022 (%)

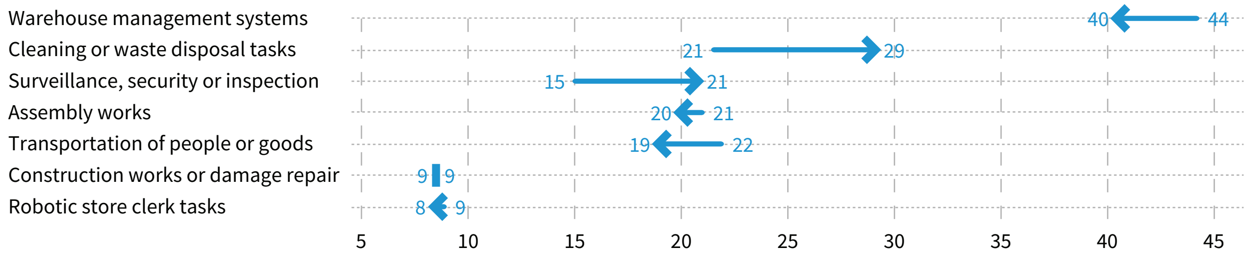


Source: *Eurostat [isoc_eb_p3d]*

However, service robots are most common in large companies in Belgium, Croatia, Denmark, Finland, Italy and Sweden, where at least 15% of companies use them. Italy also stands out compared with other countries in terms of the prevalence of service robots among medium-sized companies.

The main applications of service robots vary substantially. The most common use of service robots (just over 40% in 2020) was in warehouse management systems (see Figure 3). The technologies include autonomous mobile robots (AMRs), storage retrieval systems, packing robots and articulated robot arms. The high prevalence of these robotic technologies is not surprising given the repetitiveness of warehouse management tasks, the potentially dangerous working environments and the increasing difficulty of finding workers to perform such tasks amid increasing labour shortages. Other common applications of service robots include cleaning or waste disposal tasks and surveillance, security and inspections. Between 2018 and 2020, the adoption of these applications by EU enterprises increased. In 2020, nearly a third of enterprises utilised service robots for cleaning purposes, while around a fifth employed them for surveillance or security purposes. Less prevalent were the uses of service robots for construction works and robotic store clerk tasks. The latter involve interactive customer-facing robots that can automate several basic tasks in different environments, such as providing information to customers or clients, providing information on products or services and recording feedback.

Figure 3: Share of enterprises using service robots in the EU, by purpose, 2018–2020 (%)

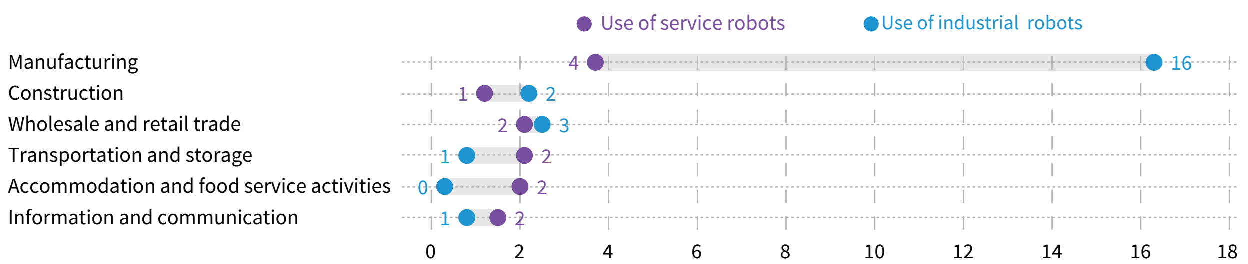


Note: *Data for 2022 are not available.*
Source: *Eurostat [isoc_eb_p3d]*

The manufacturing sector is the main industry in which both industrial and service robots are used. More than 16% of EU enterprises in the manufacturing sector use industrial robots and around 4% use service robots. The difference with other sectors is stark when it comes to industrial robots but less so when looking at the use of service robots. Notably, the use of service robots seems to be more evenly distributed across sectors (see Figure 4), which can be explained by their adaptability and their lower capital requirements than industrial robots. The figure also shows that the use of service robots in most sectors of the EU economy is at a very early stage, with only a small proportion of enterprises (between 1% and 2.5%) using such robots.

The most important factor driving the adoption of robots within enterprises is the need to ensure high-precision outputs and processes, followed by the need to increase safety at work (see Table 4). However, the EU average hides a large variation between Member States. The need to ensure the high precision of outputs and services is the most frequently identified reason for robot adoption in Belgium, Denmark and Italy. These are also countries where the need to increase safety at work and the need to expand the range of goods and services are cited by many enterprises as key reasons for robot adoption. This indicates that the choices that enterprises make with regard to introducing robots in workplaces are often driven by competing reasons. These include business concerns revolving around the quality of goods and services, competitiveness in product markets and increased productivity, but also concerns regarding working conditions, for example related to the safety of work.

Figure 4: Share of enterprises using industrial and service robots in the EU, by sector, 2022 (%)



Source: *Eurostat [isoc_eb_p3dn2].*

Table 4 shows that broader labour market trends such as wage increases and labour shortages also drive enterprises to invest in robots. The high cost of labour is cited as a reason for the use of robots by more than 4% of companies in Belgium, Denmark, Finland and the Netherlands. However, the high cost of labour drives robot adoption in Croatia, Cyprus, Greece, Ireland and Romania for around 1% of companies or fewer. While the relationship between wages and robot adoption is complex, the literature has shown that minimum wages can induce the substitution of workers for robots, particularly in low-skilled jobs (Lordan and Neumark, 2018).

Table 4: Main reasons enterprises use robots, 2022 (%)

	High cost of labour	Difficulties in recruiting personnel	To enhance safety at work	To ensure high precision of outputs and processes	To expand the range of goods or services
Austria	2.3	2.0	2.6	4.1	2.3
Belgium	5.1	4.0	6.7	8.4	4.8
Bulgaria	1.6	1.5	1.9	2.6	1.7
Croatia	0.3	1.5	1.7	2.4	2.6
Cyprus	0.6	0.7	1.2	1.5	1.3
Czechia	3.8	2.9	3.4	5.0	2.4
Denmark	5.8	3.9	4.9	8.8	3.8
Estonia	2.8	2.1	2.4	4.8	2.4
EU27	2.9	2.2	3.8	5.1	3.1
Finland	4.4	2.8	4.8	7.5	4.1
France	2.6	2.9	4.0	5.4	4.0
Germany	3.6	2.3	3.0	4.1	2.2
Greece	0.8	0.5	1.0	1.7	1.3
Hungary	1.5	1.6	2.1	3.2	1.9
Ireland	1.1	0.6	2.1	2.5	1.1
Italy	3.4	2.4	6.2	7.8	4.9
Latvia	2.1	2.0	3.4	3.9	3.1
Lithuania	3.0	2.2	2.7	3.9	2.3
Luxembourg	2.0	1.7	2.6	3.5	2.4
Malta	2.4	2.7	3.5	5.8	5.6
Netherlands	4.1	3.2	3.3	5.1	3.0
Poland	1.9	1.7	2.4	3.6	2.3
Portugal	1.6	2.3	5.8	6.0	4.4
Romania	1.0	0.9	1.6	1.8	1.4
Slovakia	2.7	2.2	4.0	5.5	3.3
Slovenia	3.9	3.1	4.9	6.2	3.9
Spain	2.9	1.6	5.5	7.0	5.0
Sweden	3.3	1.7	3.7	5.0	2.2

Source: *Eurostat [isoc_eb_p3d]*

On average, 2.2% of EU enterprises cited labour shortages as a driver of robot adoption in 2022. As evidenced by previous Eurofound research (2021a, 2023a), labour shortages are currently one of the main structural challenges in EU labour markets. These shortages stem from a combination of long-term factors, such as demographic ageing, and disparities between the supply of and the demand for skills, alongside issues related to poor job quality in certain economic sectors, such as construction and health and social care. In four countries (Belgium, Denmark, the Netherlands and Slovenia), more than 3% of enterprises cited difficulties in recruiting personnel as a reason for robot adoption. These are also countries that are faced with structural labour and skills shortages. Evidence from employer surveys also indicates that automation is considered a potential strategy in the context of tight labour markets where there is a lack of skilled labour. For example, according to the 2024 ManpowerGroup Employment Outlook Survey, one in five employers in Belgium considered automating certain tasks and processes in response to a scarce labour supply (ManpowerGroup, 2024). In contrast, fewer than 1% of enterprises in Cyprus, Greece, Ireland and Romania indicate a low labour supply as a reason for investing in robots. These are also countries where generally the prevalence of robots and the extent of labour shortages, as measured by the vacancy rate, are among the lowest in the EU.

From robots to cobots

As part of robotisation, the collaborative robots (cobots) market is projected to reach USD 16.8 billion (€15.7 billion as at 24 April 2024) by 2030, with a compound annual growth rate of 40% from 2022 to 2030 (Verified Market Research, 2023).[7] Europe – especially France, Germany, Italy and Spain – and North America collectively dominate the market, boasting the largest market shares. A substantial number of prominent players in the global cobot market are European companies. Cobots offer several key advantages, including low costs, lightweight design, high mobility, floor space savings (as cobots are typically small and compact), versatility, and easy installation and programming. These make cobots particularly well suited to adoption in small and medium-sized enterprises with constrained resources and a limited number of workers qualified for the installation and programming of robotic applications (EPRS, 2023).

Despite the many advantages of cobotic applications, the cobot market is still small. There is a need to incentivise cobot use, particularly among small and medium-sized enterprises.

Despite optimistic growth forecasts for the cobot market and the apparent advantages of cobotic technologies, the cobot market remains a relatively modest segment of the broader industrial robot market, representing only 7.5% of the total robotics market in 2021 (IFR, 2022).

Impact of robot use on working conditions

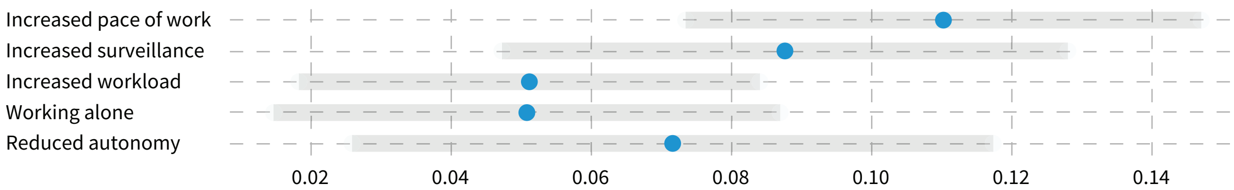
In EU-OSHA's OSH Pulse survey, about 3% of respondents in the EU indicated that they use robots that interact with humans in their main job. In contrast, a majority of respondents indicated that they use laptops, tablets, smartphones or other portable devices (73%), and desktop computers (60%). Furthermore, 5% of respondents indicated that they use machines or robots that can 'think' and make decisions, often known as artificial intelligence.

The dichotomous dependent variables in the models are derived from the following question: 'Would you say that the use of digital technologies in your workplace …?' Respondents were able to choose between the following non-exclusive options: 'increases your workload', 'determines the speed or pace of your work', 'reduces your autonomy at work', 'increases surveillance of you at work' and 'results in you working alone'. The logistic regression models also include controls for sociodemographic (gender, age and education) and work characteristics (type of contract, occupation and sector). Furthermore, to account for other unobserved characteristics that could have an impact on the variables of interest, the models include country fixed effects.

In contrast to the extensive literature examining the potential effects of robots on employment levels, empirical analyses of the implications of human–robot interaction on working conditions and psychosocial risks are much scarcer. The analysis below contributes to this area of investigation, seeking to assess whether and to what extent the use of robots (that interact with

7 The compound annual growth rate is a measure of the annual growth rate of an investment over a specified period, taking into account the impact of reinvesting the returns generated during each period of growth (i.e. compounding effects).

Figure 5: Average marginal effect of robot use on working conditions



Source: *Analysis of results from models 1–5 in Table A1, based on OSH Pulse survey data*

humans) has an impact on various subdimensions of working conditions. Figure 5 summarises the results from the analysis of the regression models detailed in Table A1 in the annex. For the sake of simplicity, the discussion of the results is restricted to only the impact of using robots that interact with humans.

The first aspect of Figure 5 worth noting is that all associations between the use of robots that interact with humans in the workplace and the indicators of working conditions are positive and significant. In terms of effect size, the largest associations are between the use of robots and increased pace of work and increased surveillance. Those who report the use of robots interacting with humans in their workplaces are, on average, 11% more likely to identify such robots as contributing to a faster pace of work, 8.7% more likely to report increased surveillance and 7% more likely to indicate reduced autonomy than those who do not report such usage. Moreover, they are 5% more likely to report a heavier workload and a greater prevalence of working alone.

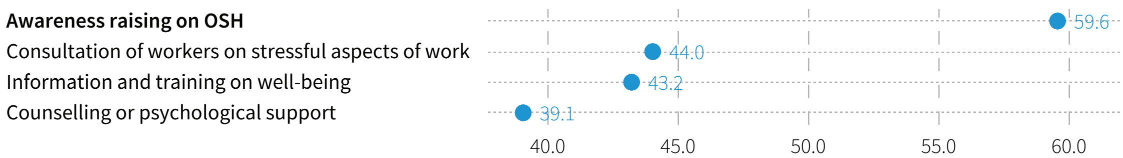
The findings suggest that the potential gains in OSH that are usually achieved when robots are adopted in the workplace (Gihleb et al, 2022) need to be balanced with the wider consequences for other aspects of work, such as working time, workload, autonomy and the risks stemming from the social environment.

Systematic monitoring of (new) human–robot collaborations is crucial for a thorough assessment of their impact on workers' well-being and productivity.

The survey also asked respondents about the initiatives in place to address and prevent OSH risks. Figure 6 shows the prevalence of initiatives in establishments using robots that interact with humans. A notable aspect is that the most common initiative is awareness raising around OSH issues, which is reported by a majority of workers using robots that interact with humans. In addition, more than 40% of workers reported that consultations occurred in their workplace regarding stressful aspects of work, along with information and training on well-being and stress management, to mitigate OSH risks.

However, the survey does not offer additional details regarding the stage of technology implementation during which consultation with workers occurred. Lastly, the least commonly reported initiative is the provision of access to counselling or psychological support. This could be attributed to the higher associated costs, compared with alternative measures.

Figure 6: Share of workers reporting initiatives to address and prevent OSH risks in establishments using robots that interact with humans, 2022 (%)



Note: *Weighted data.*
Source: *Authors' own calculations, based on OSH Pulse survey data*

Summary

- Since 2018, there has been a slight decline in the number of enterprises utilising robots in the EU, while the number of robot installations has increased. This suggests that the EU's robot market is becoming increasingly concentrated.
- Given the high capital investment requirements and the economies of scale necessary to make investments in robots profitable, large enterprises dominate the market for robots in the EU. Around 1 in 5 large enterprises in the EU use industrial robots, while only 1 in 10 use service robots. In general, the prevalence of service robots, capable of executing more complex tasks than industrial robots with a certain degree of autonomy, is much lower than that of industrial robots.
- Both service and industrial robots are mainly used in large enterprises, with the manufacturing sector leading the adoption of both types of robots. Only a small share of enterprises in other sectors are currently deploying robotic technologies.
- There are numerous motivations for companies to invest in robotic applications. Eurostat data indicate that a significant share of enterprises prioritise internal factors such as productivity, safety and competitiveness as drivers of robot adoption. However, external labour market conditions, including high labour costs and challenges in personnel recruitment, also play a significant role, particularly in countries where these issues are prominent on the policy agenda.
- EU-OSHA survey data suggest that the use of robots (that interact with humans) is associated with unfavourable working conditions, including heightened work intensity, reduced autonomy, increased surveillance and a higher prevalence of working alone. This emphasises the importance of preventing and managing psychosocial risks during the introduction and implementation of robotic technologies in workplaces.

2 Advanced robotics and human factors in technology adoption

Overview of robotic applications across sectors

From stand-alone robotic applications to integrated cyber-physical systems in the industrial sector

Human–robot interaction is most prominent in manufacturing and assembly lines, where collaborative robotic applications, known as cobots, work alongside human operators to execute specific tasks. These tasks encompass activities such as assembly, welding and precision-demanding tasks, ultimately contributing to the improvement of production quality. Cobots, however, are less suitable for handling heavy and large materials and objects, tasks for which traditional industrial robots are better equipped.

A previous Eurofound case study on cobot use in a Finnish medical device factory illustrates some of the benefits of the technology in terms of both increased product quality and improved ergonomics for shop-floor workers. Within the factory, the cobotic technology assists workers in product assembly, especially in tasks that are ergonomically challenging or demand a high degree of precision and accuracy – such as gluing small pieces, which requires a steady hand (Eurofound, 2023a). Previous Eurofound and EU-OSHA case studies on cobots in manufacturing settings exemplify the health, safety and ergonomic benefits of using cobotic applications for shop-floor workers while at the same time facilitating efficiency gains (EU-OSHA, 2023a, 2023b, 2023c, 2023d; Eurofound, 2023a). The use of cobots – and more generally smart automation leveraging cooperative systems consisting of technology and humans – is expected to increase in several industry sectors in the future, driving a shift from mass production to personalised customisation and more flexible production systems (Liu et al, 2022; Weidemann et al, 2023).

Other common robotic applications deployed in manufacturing – as identified in the screening of cases for this research – are advanced guided vehicles (AGVs) and autonomous mobile robots (AMRs). These applications involve a more moderate level of human–robot interaction than cobots, with human involvement generally limited to monitoring, supervision, maintenance and exception handling. The optimal utilisation of AGVs and AMRs occurs when they are integrated and synergistically combined with other advanced robotic technologies, including cobots. This combination is exemplified in the above-mentioned case of the Finnish medical device factory: at the time of the field visit in 2022, the factory was prototyping a mobile robot designed to move cobots between different production lines based on factory production demands. When the cobot is transferred from one assembly line to another, it automatically downloads the required software and adjusts its tools to perform the assembly tasks specific to that production line. The mobile robot uses a combination of sensors, algorithms and navigation systems to navigate the factory floor, optimising its movements and path in real time to adapt to a dynamic environment. Other case studies conducted by EU-OSHA illustrate the synergies of cobotic applications and AGVs in manufacturing environments (EU-OSHA, 2023e).

Fletcher and Webb (2017) argue that the manufacturing industry is expected to undergo a profound transformation driven by significant technological advancements in robotics and transition towards digitised and interconnected cyber-physical systems. This evolution will involve the seamless integration of any objects or components used in the manufacturing process (e.g. raw materials, machinery, equipment, tools, finished products) as well as devices and systems with computational and communication capabilities, facilitating real-time monitoring, control and process optimisation (Fletcher and Webb, 2017).

A case study conducted in a manufacturing plant in Lithuania (Box 2) illustrates the embeddedness of AGVs in an integrated advanced robotic system.

Box 2: Manufacturing plant (Lithuania) – Advanced robotics system for production, assembly and packaging

The company relocated to a new facility, designed to function as a highly automated and interconnected manufacturing environment. Using touch screens, all the robots are operated through digital workstations distributed across the manufacturing site. This advanced equipment is connected to a manufacturing execution system (MES), which allows all production activities to be monitored in real time.

The MES is programmed not only to oversee production but also to assess the quality of the final product against pre-determined standards. All manufacturing processes incorporate automatic quality-tracking, evaluation and sorting systems, ensuring that quality assurance is fully automated throughout the entire production line.

The production process starts in the warehouse, where components are precision-cut into smaller segments. These are then transported by fully automated AGVs to designated workstations for further processing. The AGVs, connected with other advanced industrial robots through the MES, receive real-time notifications about their readiness for loading and unloading the material.

At the time of the field visit, work processes in the packaging section of the plant were less automated, especially in transport activities where semi-automated guided vehicles were in operation. According to interviews with management representatives, this was expected to change later in the year, with the planned deployment of fully automated AGVs in this section of the site as well.

Source: *Eurofound research, 2023*

Interconnected robotic systems – comprising AGVs and AMRs – are also increasingly deployed in warehousing and business logistics to assist human operators in tasks such as item picking, packing, sorting and shipping. The aim is to streamline order fulfilment processes. The robots are typically connected through software solutions for real-time monitoring, optimisation, scheduling and centralised control.

The research investigated two (similar) applications in a warehousing environment (Boxes 3 and 4). An examination of the mobile shelving robot solutions implemented in these facilities revealed some elements of algorithmic management whereby warehouse workers are closely directed as to what items to pick, move, store and ship, and how to do so.

Box 3: Warehouse (France) – Mobile shelving robot solution

The mobile shelving robot solution is employed in the warehouse to pick and store items for retail orders. For picking, the operator enters an order number on the workstation screen and the robots go to the shelves holding the items and bring them to the workstation, where the operator picks up the items needed for a given order, places them in a tray and brings the tray to a control table for a final check, packaging and shipping. To replenish stock, the operator at the workstation sends robots to bring shelves with empty space, and then places new items on the shelves. Subsequently, the robots return the shelves to their designated locations. The shelves come in five different sizes (from extra small to extra large) to accommodate different-sized boxes and products.

The mobile shelving robot solution comprises mobile shelves, AGVs, workstations and software. One piece of software is employed to manage and optimise the movements of the robots, ensuring safety by halting them if there are issues. Another software system, known as the warehouse central system, is commonly used in logistics for warehouse management. The system specifies which orders require preparation, and the intermediary software establishes the connection with the inventory and the robot workstation for order preparation. This software optimises the order preparation process by ensuring that robots retrieve the maximum number of products with the minimal amount of movement, aiming for optimal efficiency.

In addition, an intermediate software solution acts as an interface between the warehouse central system and the software operating the mobile shelf system.

Source: *Eurofound research, 2023*

Box 4: Warehouse (Italy) – Mobile shelving robot solution

The mobile shelving robot solution is a complex technological solution consisting of three main physical components – that is, mobile shelving units, AGVs and workstations. The robots deployed in the warehouse assist workers in their activities by moving shelves (called 'pods') within the facility to expedite storage and retrieval processes. The robots deliver the mobile shelving units to the workstations, where operators either take inventory out (picking) or put it in (stowing).

During the picking phase, the software locates the robot that is closest to the item and directs it towards the item so that it can be retrieved. The robot navigates around the warehouse by following a series of QR codes on the floor. Each robot is equipped with sensors to avoid collisions with other robots. When a robot reaches its target location, it slides underneath the shelf and lifts it off the ground using a corkscrew action. The robot then carries the shelf to the operator assigned to picking the items; operators stand at a workstation equipped with a computer and a scanner. The computer displays the name, barcode and location of the item to pick, along with an image of the item. A light illuminates the precise bin where the item is located. In this way, the worker can easily find the item. The worker takes the item from the shelf, scans it and puts it in a tote, which is then put on a conveyor system and directed to the packing department. Once the robot delivers the product to the worker at the workstation, it goes back to its stationary position on the robotic storage platform.

When it comes to storing items, the process is reversed: the operator tasked with storing the items stands at their workstation, which is equipped with a rack for totes loaded with items to store. The robot carries the shelf, and the worker scans the item and places it on the shelf. To reduce the number of time-consuming scans that need to be conducted, a machine vision system based on deep-learning technology (trained by millions of video examples of stowing actions) is also used to offer suggestions to operators as to where to store the items.

Source: *ILO–JRC research, 2022–2023*

Together with various technologically advanced systems, AGVs and AMRs are increasingly used in port terminals to optimise cargo handling and maximise container throughput. An earlier case study of a German container terminal operator exemplifies the complexity of such systems integrating very diverse technologies and components (Eurofound, 2023a). The German container terminal employs different technological systems, including information technology (IT) and data processing systems, optical recognition systems, sensor technologies, automated heavy machinery and AGVs. Containers entering or departing the terminal, whether by train or by truck, undergo automatic identification. Cameras scan the containers' identifiers and other characteristics, while algorithms allocate containers to storage spaces, guide AGVs in transporting containers between locations and optimise the routes taken in real time. In this case, a high level of automation has transformed the nature of human interaction with technology, whereby human operators engage with computerised machines and digital devices to remotely supervise and control the machinery on the terminal ground from a control room.

Construction is another sector where the prevalence of advanced robotics is expected to increase over time as technology continues to advance. Advanced robots hold the promise of improving efficiency, bolstering safety measures and mitigating labour shortages in the construction industry. EU-OSHA research investigated a multipart technological solution designed to be retrofitted onto existing excavators, automating the trenching (excavating) process (EU-OSHA, 2023f). While the system can operate fully autonomously, it also provides flexibility, enabling the excavator to revert to manual operation if necessary. The incorporation of AI technologies into this system ensures a high level of worker safety, for example by identifying obstacles and displaying warnings to operators in real time (EU-OSHA, 2023f).

Advanced robotic applications in the health and services sectors

While several advanced robotic systems and applications that involve close interaction with workers exist in the healthcare sector, their adoption is not yet widespread. Use cases that have attracted some media attention are surgical robots currently being used on an experimental basis in some hospitals, for example in Bulgaria and Ireland (Limerick Post, 2022; Euronews, 2023). The pilots have proven successful thus far, with patients undergoing robotic-assisted surgery experiencing a reduced length of stay, reduced recovery times and improved outcomes compared with those undergoing surgeries performed without robotic assistance. Surgical robots are considered to be 'augmenting technologies', as they enable surgeons to perform complex surgical procedures with greater accuracy than traditional methods.

In healthcare settings, cobotic technologies demonstrate their inherent versatility by serving as aids for surgeons in various tasks during surgical procedures or functioning as telepresence devices, facilitating remote consultations and care.

This research investigates a more mature use case deployed in a hospital to automate the preparation and distribution of medications to various wards (Box 5). The implementation of the system may vary, based on the specific requirements of hospitals adopting the technology. However, three common elements can be identified in this system: medications are enclosed in single-unit packages, they are dispensed in a ready-to-administer form, and, typically, no more than a 24-hour supply of doses is delivered to or available on the ward at any given time (López et al, 2016).

The other case examined in a hospital setting exemplifies how cobotic technology can effectively aid staff in the handling of clinical test samples and simultaneously address shortages of healthcare workers (Box 6). This challenge is compounded by the prevalence of repetitive strain injuries among the workforce. Repetitive movements without adequate recovery time, or extended periods of standing or sitting, are recognised as factors contributing to musculoskeletal disorders among healthcare workers (EU-OSHA, 2020). The effects of these injuries are heightened in an ageing workforce, in which older workers experience more severe injuries and lengthier recovery periods than their younger counterparts. The COVID-19 pandemic further intensified the strain on healthcare workers worldwide (Bandyopadhyay et al, 2020).

Box 5: Hospital (Italy) – Unit dose system for medication preparation and distribution

Following a successful pilot in one ward, the hospital implemented a unit dose system for medication preparation and distribution across most of its wards. The system operates through three devices: two cobots – Calypso for packaging and Pegasus for preparing, storing and dispensing unit doses – alongside a piece of software connected to the cobots that receives and processes prescriptions from doctors on the wards. Once they have received the medical prescriptions and/or statistical reports on medicine supply from the wards and approval from the pharmacists, the pharmacy technicians upload the medicines onto Calypso, which creates various types of single doses from the original medication packaging.

Small bags are then loaded into Pegasus. Based on the electronic prescriptions for individual patients, Pegasus prepares the medical therapies by assembling the small bags around a ring, a physical component of the automated system. The ring consists of a bundle of individual unit dose packages. Once a unit dose of medication has been created, it can be delivered to the ward by various means, including medical staff, pneumatic tubes and AGVs.

Upon reaching the ward, the therapy is validated by the nurse using bedside scanning, which verifies and confirms its accuracy and delivery. Throughout this process, the software guarantees the complete traceability of medicines. The system encodes and manages every incoming and outgoing medication, classifying it by type, batch and quantity.

Pharmacy technicians, aided by an on-site engineer from the pharmacy's IT provider, program the machine's tasks, and medicines are stocked up at the start of the working day. Once this has been done, the system autonomously manages the schedule for producing sachets and dispensing therapies. The robotic system is fully operational daily from 8:00 to 16:00, excluding weekends, when only the preparation and dispensation of medication occur, as the engineer is not on site. However, this results in a concentration of the workload on Mondays and Fridays.

Source: *Eurofound research, 2023*

Box 6: Hospital laboratory (Sweden) – Cobot use for handling clinical samples in the pre-analytical phase

The cobotic technology was introduced in the hospital laboratory after a successful pilot. Co-developed by a cobot manufacturer, an innovation hub and the hospital's chemistry department, the cobot is a dual-arm machine featuring flexible hands, parts-feeding systems, a camera-based part location function and state-of-the-art motion control. It is controlled using a small panel, similar to a tablet. The robot's morphology is technical in all aspects (appearance, communication and movements); input communication is electronic and output communication is tactile.

The cobot is stationed in the open in the laboratory in the area where test samples are processed and catalogued, necessitating some human supervision during its operation. Staff members on duty use the robot throughout the day as part of the routine process of accepting new batches of samples that arrive from different parts of the hospital and hospital clients.

The cobot works side by side with analysts in handling test tubes. It has two main uses. It scans large numbers of test tubes to ensure the sorting and traceability of samples. It unscrews the tubes in which the samples are transported around the hospital so that the samples can be removed for testing. The cobotic technology decreased workers' exposure to the ergonomic risks associated with the handling of tubes and helped staff to deal with the substantial spike in workload and shortages of medical staff during the COVID-19 pandemic.

Source: *Eurofound research, 2023*

Cobots are known for their flexibility, adaptability and ease of programming, making them suitable for various services sectors where human–robot collaboration is beneficial (Eurofound, 2019a). Cobotics is still an emerging field of technology, but the use of cobotic applications is increasingly expanding. The cleaning industry stands out as a sector where cobotic technology is driving significant innovation (ICE Cobotics, 2023). With this in mind, this research delved deeper into the use of cleaning cobots deployed in a hospital in Spain and explored the collaborative elements of these machines (Box 7).

Box 7: Cleaning company (Spain) – Cobot use for cleaning in a hospital setting

The cleaning cobots were fully deployed by a cleaning service provider in a hospital in Spain to assist human operators in daily cleaning activities. The cobots can automatically charge, dispense and refill by themselves (when cleaning supplies run low). They move independently, following instructions uploaded by the operator at the beginning of the day. The cobots come with a charging station that only requires the operator to open the door at the start of the day and close it at the end.

The cobots clean while following the programmed route and can change direction if they encounter obstacles, including people. If the cobots consistently detect an object in their way, they will communicate this to the operator in the reports they produce at the end of the day. Although the cobots operate largely autonomously, their progress is monitored by the human operators, who intervene if there are any issues. For example, the operators can stop the system, put the cobots back on track or obtain maintenance support. The cobots can also be connected to the operator's mobile phone so the operator can be promptly informed of any issues as they arise.

In addition to the physical elements, the technology includes software designed for the cleaning activity. The software controls the movement of the cobots and ensures safety by stopping them if there is a problem. It also recognises when the cobots must return to the charging station.

The company is contemplating integrating the cobots with other hospital devices, including automatic doors and lifts, to enhance the cobots' autonomous capabilities.

Source: *Eurofound research, 2023*

Another type of robot gaining traction in the services sector is the social robot, notably in retail, healthcare, entertainment and education (MMR, 2023). The main factors driving the adoption of these robots in the services sector are technology advancements, particularly in the field of AI, and the demand for personalised customer experiences across the industries (MMR, 2023). This research explores a specific 'narrow' application of social robots in a restaurant (Box 8), prompting questions about the degree to which increased collaboration with robots may diminish the quality of interaction between employees and customers and among colleagues.

The screening process for the selection of cases also identified use cases of social robots in educational settings, albeit in the experimental or piloting stage. One example is the use of Buddy, a social robot with integrated AI capabilities. Buddy is currently used as a telepresence robot in the classroom, enabling children in hospitals or long-term care to attend school remotely. Once set up, Buddy becomes the avatar of the child, allowing them to take part in classes and interact with other students and teachers by adding movements and emotions to their messages. The child controls the robot remotely using a tablet. The desk research and pre-fieldwork conducted for this case indicated that the use of the robot affected the way teachers interacted with both children and parents, particularly when the children required assistance.

Role of human factors in technology adoption

Motivations for robotic technology adoption

The motivations for introducing robotic technologies have significant implications for human–robot interaction, shaping design choices and technology implementation. In the case of the two warehouses investigated, a primary objective was expediting order preparation and delivery. This objective is evident in the design of the mobile shelving robot adopted in both facilities, aiming to streamline the picking process, minimise human travel time and increase overall efficiency in the order fulfilment workflow. These robotic solutions are not inherently human-centric; within such systems, human operators can be seen as interchangeable components in the production chain. The workstations are standardised, and tasks are highly structured, fostering a work environment conducive to algorithmic management.

Efficiency and productivity gains were also key motivations for the adoption of robotic solutions at the Lithuanian manufacturing plant. Although the headcount at the site has remained the same, the production output and the turnover generated has grown exponentially due to greater automation. In this plant, workers receive continuous reminders through visual displays on the shop floor regarding the productivity and quality of their assigned work. These automated environments require humans to adapt and align their work with established performance indicators and work at a pace determined largely by the machines. Human centricity was not a primary consideration in the design of such automated systems.

Box 8: Restaurant (Sweden) – Social robot for table cleaning, food delivery and entertainment

Introduced to the restaurant in recent years, the robot is specifically designed to suit the needs of the catering industry. Its appearance is zoomorphic (its face and ears resemble that of a cat), while it communicates anthropomorphically. The human role is that of both supervisor and operator. The task specifications are given by waiting staff through a watch or through the robot's display; the staff can call the robot to a table and send it back to the kitchen.

The robot is commonly used in the restaurant to assist with table cleaning and delivering food to customers. It can be programmed to go to one or several tables in the restaurant. It is equipped with tray detection and 3D sensors, enabling it to move autonomously, avoid obstacles and stop automatically when needed.

Beyond interaction with staff, the cobot interacts with customers. It is programmed to provide some simple reactions and to say basic words and sentences. The cobot attracts customers to the restaurant, especially families and children, and is currently also employed for entertainment purposes.

Source: *Eurofound research, 2023*

In the case of the cleaning cobots deployed in the Spanish hospital, a key motivation for adopting the technology was to improve the quality and efficiency of cleaning services. Management envisages an increased level of automation in the future, with cobots operating entirely autonomously and potentially replacing human operators for a broader range of cleaning tasks than were previously possible.

Labour shortages motivated the introduction of the cobot in the Swedish clinical test laboratory and the social robot in the Swedish restaurant. However, there were nuances in these motivations. Management in the restaurant also viewed the robot as an opportunity to increase staff productivity, as the cobot can manage more table deliveries than an employee and is cost effective. In the hospital test laboratory, the cobot was designed to eliminate the need for analysts to perform particularly repetitive movements that could cause strain injuries – specifically the scanning, unpacking and unscrewing of test tubes. In line with this motivation, the approach chosen for technology design involved the co-creation of the robotic solution with the analysts, prioritising their needs, preferences and well-being. Similarly, previous case studies on automation conducted by Eurofound (2023a) and EU-OSHA (2023a) showcased technological solutions designed with a focus on ensuring the safety and well-being of workers. In those establishments, the automation of physical tasks was primarily aimed at diminishing unnecessary workload, alleviating workers' physical strain and fostering a more ergonomic work environment overall.

Increasing patient safety and medication traceability was the primary motivation for adopting the unit dose system of medication preparation and distribution in the Italian hospital. This technology minimises human error in dispensing medicines, consequently reducing cases of rehospitalisation due to incorrect therapy administration. Alongside safety concerns, the intention was also to reduce time spent dispensing medicines and free up time of pharmacists and nurses for patient-facing work. The adoption of state-of-the-art technologies also reflects the hospital management's commitment to being at the forefront of technological innovation.

The cases that were investigated reveal a variety of motivations for the adoption of robotic solutions, ranging from boosting productivity and competitiveness to addressing labour shortages, improving employee safety and well-being, and, in the case of the unit dose system in the Italian hospital, ensuring high standards of patient care and safety. Improvements to working conditions were highlighted as a secondary motivation in most case studies in this research. Though commonalities exist, each case illustrates unique motivations tied to industry dynamics, shaping the degree to which human factors are taken into account in the design and implementation of the technologies adopted.

Motivations for technology adoption influence technology design. An overemphasis on productivity may overlook the potential for meaningful human–robot collaboration.

In line with the motivations for technology adoption, the prevailing approach to adoption in most establishments involved assessing the suitability of tasks for automation. Typically, the approach was to rely on workers for tasks that were either too costly or challenging to automate (at least at that time). This approach, however, has its limitations, as it is assumed that workers will be relegated to temporary or auxiliary roles in the process of automation. Overcoming this perception is crucial for the successful implementation of human–robot collaboration, particularly in terms of ensuring workers' acceptance and trust in newly introduced technologies (Petzoldt et al, 2023).

Risk assessments and piloting

Conducting risk assessments and implementing preventive measures are essential for identifying and managing the potential risks to health and safety at work and are legally mandated for employers under Article 9 of the OSH Framework Directive (Directive 89/391/EEC). This requirement is particularly pertinent in the context of robotic systems or applications involving human–robot interaction. EU-OSHA (2022a) emphasises the importance of involving workers in risk assessments, establishing open communication channels for reporting hazards or concerns, and engaging workers in decision-making regarding safety measures. Previous Eurofound research highlights the significant role of risk assessments in the adoption of advanced robots in companies taking an ethical approach to digitalisation (Eurofound, 2023a). This was particularly apparent in the case study of a Finnish medical device manufacturing site, where all production lines undergo monthly risk assessment procedures whereby both the physical and the psychosocial work environments are assessed (Eurofound, 2023a).

In EU-OSHA case study research on automation, stakeholders interviewed in selected establishments pointed to the need for comprehensive risk assessment tools that reflect the current abilities and limitations of today's technologies (EU-OSHA, 2023a). In their experience, the available tools for risk assessment were perceived as lacking flexibility, and were insufficient and not suited to the technologies. These establishments dealt with such shortcomings by conducting their own internal risk assessments, which were reportedly stricter and more detailed than those required by law.

In most of the establishments investigated in this research, risk assessments were also an integral part of testing robotic systems or applications. For instance, in the case of the manufacturing plant, creating a safe working environment was a priority for management when designing the new factory. Prior to the implementation of the robotic system at the new site, risk assessments were undertaken to identify potential safety hazards.

Comprehensive risk assessments were conducted before deploying the cobot during the pilot phase in the Swedish clinical test laboratory, ensuring compliance with safety standards and optimal human–robot collaboration (without necessitating separation or barriers between the robot and humans). Specific design considerations were made, such as smoothing the exterior shell of the robot by giving it fewer corners and lines. This design choice aimed to prevent the accumulation of bacteria, increase the effectiveness of cleaning processes and enhance the safety of analysts. Scholars increasingly advocate for a thorough risk assessment, particularly for cobotic applications. This would assess not only the robot system itself but also the environment in which it is deployed, with special consideration for potential operators (Pauliková et al, 2021; Adriaensen et al, 2022). This suggests a shift away from a techno-centric to a more human-centric approach to ensure the safety of those in proximity to robots.

However, in the establishments investigated, risk assessments were often conducted as one-off exercises, performed at the time when the technology was adopted. The primary focus was on guaranteeing the physical safety of workers. Other human factors, such as those of a psychosocial nature, important in human–robot interaction were often overlooked. In some instances, as in the case of the cleaning cobots used in the Spanish hospital, the management representatives interviewed were unaware of any risk assessments conducted prior to the rollout of the technology. Nonetheless, they expressed confidence in its safety, citing successful testing in other industries. Similarly, in the French warehouse investigated, no specific risk assessment was conducted for the mobile shelving robot, as it holds a CE certification from an independent body. This certification indicates that the robot is deemed sufficiently safe and well designed, posing no risks during normal use and when operators adhere to the instructions provided.

Both the performance of risk assessments for safety testing and the piloting of the technologies were often orchestrated by IT providers, sometimes off site, typically with minimal or no involvement from the workers directly affected by the technology. The case of the Swedish clinical test laboratory stands out from the rest in this respect, as there was active employee involvement in both the risk assessment and piloting of the cobotic technology. The IT provider worked on site in the laboratory during the piloting phase (which included a broad risk assessment and needs assessment), interacting with staff and management to understand and adapt the technology to ensure that health and safety standards were met and that the robot was programmed and used in the most effective way. The approach adopted in this establishment demonstrates that human centricity and human factors can indeed be considerations in the adaptation and customisation of robotic solutions developed by third parties. However, this process requires significant time and collaboration between IT developers or providers and the establishments where the technology is deployed and used.

In all other cases, the main goals of the testing and piloting phases were driven mainly by technical considerations, ensuring the technology's alignment with the organisation's objective of increasing productivity, efficiency or service quality. Ensuring the human-centric design of the technology was often not considered.

Training provision

Training provision and the development of appropriate skills play a vital role in ensuring OSH in the context of human–robot interaction. In this regard, EU-OSHA advocates for comprehensive training programmes to improve workers' understanding of robotic systems, their operation and associated risks (EU-OSHA, 2015). EU-OSHA research also draws attention to the importance of educating workers not only on how to operate a machine but also on the potential benefits for them, such as avoiding strain injuries or gaining more control over their time (EU-OSHA, 2023a).

Based on case study evidence, the training provided in the context of the adoption of robotic technologies is typically narrow in focus and designed to equip workers with the skills required to use or interact safely with the specific technology (Eurofound, 2023a). Training provision is less often integrated into comprehensive change management programmes to assist workers in better adapting to new roles and work practices resulting from increasing human–robot interaction (Eurofound, 2023a). This was also apparent in the case studies investigated for this research, although the establishments did implement various training approaches as part of the adoption of robotic applications.

It is not enough to train workers to use robotic equipment safely. Upskilling, akin to change management, plays a central role in fostering workers' adaptability in the face of constant change.

In the two warehouses investigated, training is generally provided upon hiring and is subsequently available on demand or when new technologies are integrated into the robotic system. The primary focus of this training is to ensure the safe and correct use of the robotic solutions. Moreover, the training – whether provided in-house or by the technology provider – is tailored to specific roles, for example warehouse operator, team leader, line manager or other more technical positions. In both warehouses, operators generally acquire hands-on experience in using the technology on the job, with senior operators acting as coaches for more junior staff. However, according to the members of management interviewed, warehouse operators require no specific training or skills to operate the technology; they are directed or guided by the robotic system as to the sequence of tasks to perform.

On the manufacturing site, machine operators learned to use the new equipment through information booklets, communication sessions and technology demonstrations with senior operators. The operators interviewed voiced concerns about both the duration and the quality of the training provided, expressing a preference for mentoring and more hands-on training over demonstrations of how the new equipment works and should be used. An effective approach to training may involve shadowing assignments, internal apprenticeships and trial periods. From the perspective of workers, the approach to training should be reviewed, especially considering that more processes on the shop floor are expected to be automated in the near future. According to the employees interviewed, the company should also encourage opportunities for shop-floor workers to learn how to operate various types of advanced equipment, thereby expanding their skillsets. Mandatory specialisation in operating a single type of equipment hinders operators from acquiring new skills, thus diminishing their interest, flexibility and adaptability and limiting their professional growth and development.

Concerns regarding training provision were also expressed by nurses at the Italian hospital investigated during the implementation of the unit dose system. In this instance, training was delivered on site by a representative of the technology provider and a trained hospital pharmacist exclusively to pharmacy technicians. Although pharmacy technicians received training to operate the robotic system, they were not authorised to perform maintenance, as the training did not cover routine maintenance. This led to some overreliance on the IT provider’s on-site technician. Nurses gained familiarity with the new medication dispensation system over time. From their perspective, training provision tailored to their needs could have helped them to overcome their initial resistance towards the adoption of the technology.

Greater emphasis on training provision was observed at the Swedish clinical test laboratory, where analysts using the cobot are required to undergo extensive training to operate and supervise the technology; upon completing the training, they acquire a special licence to use the cobot. Analysts using the cobot are also trained in handling unexpected situations should they arise. For those new to the technology, training is provided over six months by a senior analyst, who acts as a supervisor or mentor on a one-to-one basis. The training programme includes various levels: some staff receive basic training and are qualified to operate the cobot, while others undertake intermediate or advanced training to enable them to offer assistance or advice and troubleshoot in the event of issues. Fully trained analysts also undergo refresher training sessions, particularly after returning from leave. According to the staff interviewed, the training is perceived as both necessary and a positive addition to their job, given the level of sophistication of the technology. An additional benefit for them is the acquisition of new digital skills.

The cleaning cobots used in the Spanish hospital and the robot used in the Swedish restaurant were stand-alone robotic applications that did not need to be integrated into complex IT infrastructure, and, according to management, workers did not require extensive training to use them. In the case of the cleaning cobots, a single training session on how to operate and supervise the cobots was provided to cleaning staff who volunteered to take up the role of cobot operator. In the case of the robot deployed in the restaurant, management did not provide any training for staff, as the use of the robot was optional and therefore it was up to the waiting staff whether they learned how to use it. The assumption was that most people have a certain level of familiarity with automated and digital tools, which is not necessarily the case. The restaurant staff interviewed had mixed opinions about this approach, with some feeling comfortable exploring the technology on their own and others (older and more experienced staff) being more reluctant to use the robot. The latter often saw the technology as a gimmick and, in some instances, even as undermining their role as professionals.

Overall, in the establishments investigated, training was not perceived as a means of empowering and upskilling workers in preparation for future automation-related changes. The reluctance to upskill workers could stem from various factors. For instance, implementing comprehensive training and upskilling programmes may entail significant costs for organisations, including expenses for developing training materials, instructor fees and employee downtime. In addition, dedicating resources to training and upskilling may redirect financial and personnel resources from other critical business areas. Beyond resource considerations, the process can be complex, requiring the careful identification of appropriate training methodologies and content and a suitable duration to ensure effective skills development.

Employee involvement and social dialogue

In line with Directive 2002/14/EC of 11 March 2002 on informing and consulting employees, national legislation requires employee representatives to be consulted about significant changes to work organisation and working conditions; technology innovation is, however, not always explicitly specified in national legislation as a driver of such changes.

In all the cases investigated, the decision to introduce the robotic technology was taken by top-level management, with employees and their representatives being informed of rather than actively consulted or involved in the decision-making about the adoption of the technology. Similarly, previous research on automation (Eurofound, 2021b, 2023a; Cirillo et al, 2022; ILO and JRC, 2024) found limited involvement of trade union and works council representatives in decisions concerning technological change; they saw their role as concerned with the management of outcomes of automation rather than technology implementation.

Research by EU-OSHA on automation indicates that clear and direct communication fosters change-supportive behaviour among workers and promotes the acceptance of robotic technologies (EU-OSHA, 2023a). Based on the research findings, EU-OSHA advocates for continuous communication even after the technologies are implemented, emphasising the importance of keeping communication channels open to respond effectively to any emerging changes.

From a management perspective, the decisions around technological change in the establishments investigated in this research, especially in those implementing more advanced and interconnected robotic systems, were aligned with an overarching company digitalisation strategy already known to employees and their representatives. Furthermore, in most establishments, it was deemed that the adoption of technological solutions did not introduce drastic changes to work organisation and therefore did not necessitate negotiations between management and worker representatives. In the Italian warehouse, management also cited a need to standardise negotiations nationwide, with no distinction made between traditional and robotic warehouses, to guarantee the same treatment for all operators regardless of the site where they were employed.

Overall, there were no major pushbacks from worker representatives, who were generally satisfied that the robotic solutions adopted would contribute positively to the physical work environment, and, as in the hospitals investigated, ensure high health and safety standards for both workers and patients. However, in most establishments, worker representatives played an important role in articulating and conveying to management workers' concerns or feedback related to the implementation of new technologies. Concerns frequently centred on potential job displacement due to automation and, particularly in the case of cleaning cobots, fear of handling expensive equipment and the risk of causing damage. These concerns were less apparent in the two warehouses and the Lithuanian manufacturing site, where the robotic solutions adopted were the most advanced. In these establishments, the workers interviewed acknowledged the inevitability of increased automation in those settings. They also viewed working in a highly automated work environment as an opportunity to acquire valuable experience, and therefore beneficial for securing employment in other companies in the same sector.

In establishments other than the two warehouses, open and transparent communication on the part of management regarding the reasons and timeline for introducing the technology were cited as an important enabler for its smooth implementation, with line or HR managers often playing an important role. In the case of the cleaning cobots deployed in the Spanish hospital, technology adoption was facilitated by a long-standing and well-established relationship that cleaning staff had with their HR manager at the hospital. The interviews with employees showed that acceptance of the cobotic technology in the hospital largely depended on their trust in their HR manager and the manager's ability to effectively communicate the benefits of the technology. Management at the cleaning company reportedly faced significant difficulties when attempting to introduce the same technology in other establishments where they operated due to resistance and pushback from workers on site.

In the case of the Italian hospital that introduced the unit dose system, insights from focus groups with staff revealed that the actual implementation of the robotic system for medication preparation and distribution could have been more effective if certain features of its design had been discussed with pharmacy technicians and nurses during the design stage.

In most establishments, greater worker involvement at various stages from technology design to implementation would have increased trust in the technology and alleviated some initial concerns. Past research has recognised trust as a key factor in human–robot interaction (Charalambous et al, 2016), influencing the use of automation and the success of human–robot collaboration (Baltrusch et al, 2022).

A factor that probably diminished the level of direct participation of workers in the concept formation and the technology design stage was that, in most instances, the robotic solutions were not internally designed and developed. Instead, an external IT provider or, in the case of the Italian warehouse, a company within the same group but located elsewhere, designed and developed the technologies. According to the management of the Italian warehouse, having a dedicated team responsible for developing new robotic technologies for all establishments enables the company to operate in a coordinated manner. This involves developing a single technology to be implemented at different sites to address similar problems. This approach eliminates the need for technicians to devise a new solution from the ground up each time a problem occurs and allows the rapid estimation of the potential benefits of the new technologies on a broad scale. However, such a standardised approach to technology design and implementation may not fully align with human-centric principles.

Treating workers as co-creators of or contributors to technological solutions is key to effective human–robot interaction.

Nonetheless, workers in the establishments investigated were often encouraged to provide feedback and play an active part in finding solutions or fine-tuning the technology once it was fully rolled out. For example, at the Lithuanian manufacturing site, workers are routinely incentivised by salary bonuses to make suggestions to improve systems or identify and report to management any issues related to health and safety or affecting the productivity of the production lines they are assigned to. In the Italian warehouse, several digital tools are available to warehouse operators enabling them to provide feedback (including remotely) on the safety of the robotic system or to make suggestions for improving its functionalities. On the surface, this feedback mechanism seems valuable, as it gathers insights directly from workers, drawing on their accrued practice and work experience. However, this knowledge is likely to be utilised for the automation of more work processes. While this is speculative, it raises concerns about potential job displacement and the perception of workers in such robotic warehouses as disposable or interchangeable components of a production chain.

Summary

- The adoption of robotic technologies is driven by various motivations, shaping human–robot interaction and influencing design choices and implementation. Efficiency and productivity gains were the main motivations for technology adoption in the establishments that were operating more complex robotic systems. Improvements to working conditions were highlighted as a secondary motivation in most case studies. Human centricity was not a primary consideration in the design of the robotic systems and applications investigated.
- In line with findings from previous case study research on automation, risk assessments for robotic systems focused primarily on physical safety in most of the establishments investigated. In addition, they were often conducted on a one-off basis at the time of technology adoption, with limited consideration for other human factors in human–robot interaction. Safety testing and piloting, typically led by IT providers, generally lacked direct worker involvement. In cases where employees were more actively involved in risk assessments or piloting, the primary focus was on technical considerations rather than ensuring human-centric design. Gaining workers' perspectives when introducing robots to workplaces is essential for enhancing human–robot interaction.
- The case study evidence highlights a focus in training on ensuring the safe and correct use of robotic solutions, with more tailored training for specific roles. The training is often led by senior staff. Notably, training provision across establishments was not integrated into comprehensive change management programmes aimed at assisting workers in adapting to new roles and work practices resulting from increasing human–robot interaction.
- Research on automation, and more broadly digitalisation, has consistently demonstrated that a participatory approach to technology adoption fosters trust and a sense of co-responsibility for safety and efficiency among workers, and increases their acceptance of the technology. In all cases investigated, the decisions to introduce the robotic technology were made by top-level management, without the active consultation or involvement of employees or their representatives. Worker representatives generally viewed the technologies positively, stating that they increased workers' safety and reduced physically demanding tasks. They therefore did not resist or object to the technology being adopted. The representatives played an important role in communicating workers' concerns, particularly about potential future job displacement, to management. Most pressing concerns were most effectively addressed by line managers or HR managers with established relationships with workers built on mutual trust.

3 Impact on work organisation and working conditions

Changes to work organisation

Depending on the sophistication of the robotic system or application, closer human–robot interaction brings about changes in various dimensions of work organisation to varying extents. Evidence from the case studies investigated suggests that the areas most affected are workflows and workspace design, along with task definition, allocation and content. In some establishments, the shift from manual and routine tasks to more analytical or technical tasks generated new skills requirements. This is not consistently addressed through training provision, but is evident in changes in hiring requirements. In some other establishments, the use of the robotic systems or applications did not require specific skills; however, this does not rule out the possibility of providing associated training, with an emphasis on opening up new career trajectories and aligning with establishments' future automation plans, involving upscaling technologies.

Another important aspect of robotic systems is the inevitable collection, processing and distribution of real-time and granular data through a distributed system involving multiple robots, interfaces, sensor technologies and humans operating such systems. The investigation of the technology systems deployed in all establishments revealed the potential for leveraging data to closely monitor workers' activities beyond team or shift performance, or at establishment level, as suggested by management.

Workspace redesign and changes to workflows

Production processes and work systems undergo a gradual transformation from traditional layouts and configurations through the incorporation of human–robot collaboration (Weidemann et al, 2023). In the establishments implementing more complex, interconnected and ubiquitous robotic systems – such as the two warehouses, the manufacturing site and the Italian hospital – the introduction of robotic technology necessitated substantial workspace redesign and changes to existing workflows. When planning new sites or reconfiguring existing workspaces, managers who were interviewed emphasised that ensuring a safe work environment, and not focusing solely on high productivity, was a priority. Ergonomic considerations were identified as fundamental elements of the workplace design process. An important requirement for such systems was to improve overall ergonomic working conditions, by opting for a design that minimised the physical workload for the operators.

In these establishments, the design or redesign of the workspaces to accommodate the robotic technology also necessitated elaborate upstream preparations. The managers interviewed in the Italian warehouse also acknowledged that cutting-edge technologies require continuous improvements, hence the importance of incorporating workers' feedback in the process of technological change.

In addition to some redesign of the physical workspace, the deployment of the unit dose system in the Italian hospital required a thorough reorganisation of internal workflows. This was necessary as the robotic system would take over a significant portion of therapy production and distribution. The location and dimensions of the robotic applications, as well as their impact on the workspace and workflows, were considered during the conceptual and design stages. However, challenges arose during the implementation phase for both pharmacy technicians and nurses. Pharmacy technicians operating the robotic systems faced difficulties in reaching some automated parts for restocking medicines due to the system's design. Meanwhile, the primary challenge for nurses was the co-existence of a conventional method for collating patients' therapies from dispensing cabinets. This conventional method is employed, for instance, when certain drugs, such as drip bags for intensive care, cannot be managed through the robotic system.

The deployment of the cleaning cobots in the Spanish hospital did not necessitate significant redesign of the workspace. However, it affected internal workflows for cleaning staff, as the cobots took over a significant portion of cleaning duties. This led to adjustments in cleaning schedules and the rerouting of cleaning paths for the cleaning staff.

Other more discretionary robotic applications investigated in this research – such as the social robot deployed in the restaurant or the cobotic technology used in the Swedish clinical test laboratory – did not involve significant changes to workspaces or existing workflows. As these applications are designed to interact in proximity with humans, they adhere to stringent safety requirements and are CE-certified by external bodies, ensuring compliance with EU safety standards.[8]

Task definition, allocation and content

Empirical research on automation found that industrial robots currently employed in Europe are more advanced versions of previous automation technologies (Fernández-Macías et al, 2020). There has not been any significant discontinuity or disruption in terms of the types of tasks they can perform, and they still focus primarily on physical tasks. Furthermore, the research suggests that there has been minimal change in the nature of these tasks, which continue to be relatively routine and standardised. Acemoglu and Restrepo (2018) also argue that technologies posing the most significant threat to labour are not necessarily major breakthroughs that drastically increase productivity. Instead, the greatest threat arises from technologies that are sufficiently advanced to be adopted but not so advanced that they substantially boost productivity.

According to Autor et al (2003), advancements in technology have facilitated the substitution of workers engaged in routine tasks, a phenomenon often referred to as the 'routine-biased technological change hypothesis'. While the robotic technologies employed in the establishments investigated automated several manual and routine tasks, there is still a substantial number of tasks for workers to do, mitigating any threat to their jobs (at least in the short term).

The case studies also illustrate the extent to which advanced robotic technologies can alter task definition, content and allocation. Overall, the findings align with previous EU-OSHA case studies, demonstrating that the automation of repetitive and monotonous tasks by robotic systems and applications in the selected establishments led to the transformation of job routines for workers. This transformation resulted in increased task variety and a shift towards more problem-solving-oriented tasks, demonstrating clear potential for enriching the overall content of work (EU-OSHA, 2023b, 2023c, 2023d, 2023f).

At the manufacturing site, an extensive transformation in the nature of tasks performed by shop-floor workers was also observed. There was a shift from physical tasks to tasks involving the monitoring of the performance and productivity of equipment. Shop-floor workers' tasks therefore became less repetitive and more focused on problem-solving, reducing the amount of routine work they had to do. Consistently with the findings from a qualitative study by Pfeiffer (2016) in German manufacturing plants, automation increased job complexity. To avoid significant flaws in quality and productivity and to sustain an uninterrupted overall process, human intervention, organised in shifts, becomes necessary. This requires workers to possess qualifications and knowledge of processes gained through experience, which, according to Pfeiffer, cannot be reduced to mere routine work.

The success of implementing advanced collaborative robotic systems hinges on the careful consideration of how and which tasks are (re)allocated to humans.

Substantial changes to the nature of work and the allocation of tasks were observed in the two warehouses investigated. Operators no longer walk around the warehouses manually picking or stowing items; instead, they remain stationary at their assigned workstations, carrying out picking and stowing tasks as directed by the robotic system, while area or operations managers supervise processes and workers' activities. The system is responsible for scheduling and allocating resources to different tasks (i.e. stowing, picking and packing) based on an overview of the volume of products in the warehouse. Area or operations managers, however, retain some discretion and may adjust the system allocation if necessary, considering inbound and outbound volumes.

In the Italian hospital, the adoption of the robotic system triggered substantial changes in task content for both pharmacy technicians and nurses. Prior to the deployment of the unit dose system, pharmacy technicians were in charge of placing medicines in the cabinets and preparing specific medications, while nurses assembled therapies manually to dispense to patients. The tasks of pharmacy technicians now include operating and supervising the robotic system, and loading the necessary stock of medicines onto it. According to the pharmacy technicians interviewed, these tasks are perceived as more cognitively demanding than their previous responsibilities. Nurses recognised that the unit dose system is capable of flagging inconsistencies and errors, thereby mitigating the risk of human error when dispensing medication. The time freed up for nurses by the medication dispensation system was redirected towards high-value-added and patient-facing work, ultimately improving the quality of care. Similar findings emerged from previous case study research on pharmacy robotics, highlighting a shift from routine pharmacy tasks to high-value-added, patient-facing work (Findlay et al, 2017).

8 A specific standard for collaborative robots (ISO/TS 15066:2016) was established in 2016. This standard outlines safety requirements for collaborative industrial robot systems and the environment in which they work, and supplements the requirements and guidance on industrial robot operation provided in ISO 10218-1:2011 and ISO 10218-2:2011.

In other establishments, the introduction of technology led to the redistribution of tasks for certain workers. For instance, with the deployment of the cleaning cobots in the Spanish hospital, cleaning staff were relieved of some tasks, such as sweeping and mopping large floor areas. Instead, they were assigned more detailed cleaning tasks requiring dexterity, or other activities that had not yet been automated (but with the expectation that they would be automated relatively soon). Those responsible for operating the cobots also assumed additional responsibilities, such as the daily supervision and cleaning of the cobots, addressing minor mechanical issues and liaising with technical experts to resolve more complex malfunctions.

Similarly, in the Swedish test laboratory, the introduction of cobots only partially altered the tasks performed by analysts, although not to the extent that their job could be fully automated. In addition to supervising the cobots during operation, analysts can now make more efficient use of their time, concentrating on more analytical tasks. Use of the cobots is also discretionary, and analysts can choose whether or not to use them.

In the restaurant, the use of the social robot is also optional; it is up to front-of-house staff to decide when to use it to assist them with various waiting tasks. However, more experienced staff members were more reluctant to use it, preferring to maintain direct customer contact while serving food and drinks. The use of the robot did not affect the tasks of back-of-house staff working in the kitchen in any way.

Workplace monitoring and control

The capturing of human data (whether direct or indirect) and the monitoring of workers' activities through digital devices and sensor technologies in Industry 4.0 work environments pose threats to human dignity, data protection and privacy (Eurofound, 2022). Past Eurofound research has drawn attention to the expanded monitoring capabilities of state-of-the-art digital technologies, pushing the boundaries of what is necessary, legitimate and permissible (Eurofound, 2020a). The risk of privacy and data protection breaches is heightened in interconnected and highly digital work environments. This is particularly the case in the absence of consultation with workers before technology is implemented or clear governance around employee monitoring and surveillance (Eurofound, 2021c). The use of digital technologies for monitoring and controlling workers also raises the spectre of a new 'digital panopticon' where workers are continuously visible to their employers, leading to a deterioration in employment and working conditions (Manokha, 2020). Furthermore, in work environments where the technology is fully embedded in work processes, workers cannot opt in or out of the monitoring, be it at establishment, team or individual level. Monitoring becomes an inherent aspect of working in such environments and a feature of the robotic or digitised systems that is taken for granted.

In the establishments investigated, especially those integrating advanced and interconnected robotic systems, a sophisticated IT infrastructure is in place, relying on the real-time collection and processing of extensive data about workers' activities at a high level of granularity. At the manufacturing site, production processes were monitored to facilitate the delivery of toolboxes to shop-floor workers for the management and optimisation of work processes.

In establishments deploying stand-alone robotic applications, such as the cleaning cobots in the Spanish hospital, there are plans to expand the technology further. This involves connecting the cobotic technology with other IT systems and introducing AI-powered functionalities to manage, monitor and assess the hospital's cleaning activities and requirements. A notable aspect of this technology is the ability of the hospital's patients to provide ratings for the cleanliness of different areas. While workers did not explicitly express concerns about adopting this new system, there was a sense of uncertainty or uneasiness at the prospect of having their performance reviewed in this manner. The cleaning company also envisages deploying other cobots at various sites where they operate. According to management, monitoring work activities will become more streamlined, requiring less human involvement and enabling the monitoring of the performance of employee groups across different locations. In other establishments investigated, future plans invariably involve scaling up the technology, often leveraging AI capabilities. This may give rise to more data-centric management and control practices.

While the establishments investigated confirmed that they complied with GDPR rules, decisions regarding data collection, processing and storage are predominantly influenced by technological design (and are dictated by set performance metrics or key performance indicators) rather than guided by a comprehensive data governance policy. Furthermore, complying with principles of data minimisation and proportionality, as set out in the GDPR, can be challenging in highly automated and interconnected work environments reliant on the collection and processing of large amounts of data to operate.

In both warehouses investigated, the robotic systems provide accurate data related to productivity, in particular the number of orders processed and the number of items stowed and picked. These data are then used to manage the workload of warehouse workers. Similarly, the robotic system in operation at the Lithuanian manufacturing site collects and processes detailed data about the volume and quality of orders being produced and the processing time involved. Although it is technically feasible, the establishments denied using the collected data to monitor and measure individual productivity; such monitoring is reportedly done at the team (or production line) and establishment levels.

None of the establishments requested or conducted data protection impact assessments, even though some of the systems deployed inevitably involve the capture of human data, either directly or indirectly. While not always mandatory, when performed, data protection impact assessments signal to the workforce the organisation's commitment to data protection and respect for workers' privacy.

Changes to working conditions

As robots and automation become integrated to a greater degree into various industries, it is crucial to consider not only the efficiency gains but also the implications of more complex human–robot interaction for working conditions. Prioritising job quality in human–robot interaction is pivotal for creating a workplace that is not only technologically advanced but also human-centric. Various facets of job quality are prominent in human–robot interaction, particularly intrinsic aspects of work quality (such as autonomy, skills and social support) and OSH. Considerations also extend to working time and work intensity, and overall employment quality, encompassing earnings and career prospects. Previous research identified four specific job quality-related factors that are of relevance to human–robot interaction. These are cognitive load; collaboration fluency (closely related to the timing of tasks and perceived efficiency); trust in robotic technologies; and acceptance of and satisfaction with the technologies (Baltrusch et al, 2022). These aspects are also explored in this research, particularly in the sections on job discretion and OSH.

Effective human–robot interaction goes beyond technical issues and safety considerations. It necessitates a focus on aspects of job quality.

Job discretion

Measuring autonomy is complex, as it encompasses various aspects. These include the monotony of tasks, control over the way and when tasks are completed, and flexibility. Previous case study research suggests that workers need to adjust their behaviour and work routines to accommodate robots, for example waiting until the robot completes its tasks (Wurhofer et al, 2015; Baltrusch et al, 2022). This limits their freedom to decide how and when to perform their job. A previous Eurofound case study involving the deployment of cobotic technology in a Finnish medical device factory showed that the technology slowed down the pace of work. This caused some frustration among shop-floor workers, arising from the need to wait for the cobot to finish its tasks before they could initiate their assigned tasks (Eurofound, 2023a).

Drawing on the employment surveys conducted by the German Federal Institute for Vocational Education and Training and the German Federal Institute for Occupational Safety and Health in 2006, 2012 and 2018, Meyer et al (2019) provide some evidence of new manufacturing and processing technologies reducing workers' autonomy.[9] In assembly lines and production environments, work allocation is structured around formalised procedures and a pre-defined set of tasks. The high level of standardisation – required in an automated work environment – further constrains discretion over tasks and work methods for those operating robotic systems. However, contrary to expectations, a higher level of automation in the Lithuanian manufacturing site enabled some greater autonomy on the shop floor, as an important part of the job of system operators is to respond quickly to arising issues and implement corrective actions on the basis of the data collected by the system. The robotic system collects and processes large amounts of real-time data, which inform decisions taken by operators, for example, to optimise work processes, to identify bottlenecks on any production line and to implement the necessary improvements, and, ultimately, to increase the overall productivity of the system.

In the warehouses investigated, the robotic systems were designed to instruct workers – who are assigned to each workstation – what items to pick, move, store and ship and how to do so. A machine vision system informed workers of exactly where they were to place items. Workers' autonomy is inherently constrained by the nature of their work, and automation further curtails their discretion. Robotic systems, which are increasingly prevalent in warehouses, facilitate algorithmic management, automating specific managerial functions. For example, they instruct workers what tasks to do and how and when to perform them, and facilitate the evaluation of workers' performance (Eurofound, 2022).

In both the manufacturing site and the warehouses investigated, workers are expected to adjust to the robots' movements, rather than the other way round.

9 The employment surveys conducted jointly by the German Federal Institute for Vocational Education and Training and the German Federal Institute for Occupational Safety and Health consist of telephone interviews conducted at six-year intervals with 20,000 employed individuals.

The robotic solutions adopted are designed to leave limited room for adjustment to workers' needs and preferences. On a positive note, robots' goals and movements in such settings are perceived by operators as highly predictable. This is considered an indicator of collaboration fluency in human–robot interaction research; by making robot movements repetitive, consistent and predictable, operators' situational awareness is heightened, leading to greater acceptance of and trust in human–robot interaction (Baltrusch et al, 2022). Ideally, human-centric robotic solutions should not only exhibit predictability in their goals and movements but also deliver a distinct advantage to humans, minimise negative experiences and provide an interface that can be adjusted to the operator.

In the case of the robotic system adopted in the Italian hospital, pharmacy technicians feel they are strongly dependent on the machine's functioning. They also mention that their autonomy is somewhat constrained, as they need to be attentive to every minor issue the machines encounter to prevent malfunctions. Despite the system's near-full autonomy, the IT provider's on-site technician must be on hand to monitor and intervene when issues arise, which is seen as interrupting their workflow.

In other establishments adopting stand-alone robotic applications – whose use was discretionary, for example the social robot in the restaurant or the cobot in the hospital test laboratory – workers' autonomy was not affected, as the technology was viewed as helping them to accomplish their work.

Similarly, in the case of the cleaning cobots deployed in the Spanish hospital, the technology did not significantly impede the ability of cleaning staff to take breaks when they wanted or needed to; rather, it had a positive impact, as it helped them to reduce their workload and have a more relaxed working day. However, a degree of human supervision is still required. While the cobots are nearly fully autonomous, they alert human operators through an app on their mobile phone when they encounter any issues that prevent them from completing cleaning tasks. Operators must then pause their activities to assist the cobots. However, operators can perform other tasks while the cobots are cleaning, remaining available to provide support if and when necessary.

Skills use and skills requirements

The introduction of a new generation of robots, which can be programmed through manual input devices, has increased the need for specialised skills in robot handling and maintenance and technical knowledge of robot functioning (Andelfinger and Hänisch, 2017).

There is also a growing emphasis on supervisory, organisational, collaborative and social skills for coordinating complex work processes effectively (Bragança et al, 2019). As humans still possess superior reasoning, decision-making and social judgement abilities to robots, workers are expected to assume more leadership and supervisory roles on the shop floor. As Krupitzer et al (2020) note, this implies that the new skills requirements are becoming both more specialised, including technical skills, and more generalist, including social and interdisciplinary skills. Recognising the importance of reskilling and upskilling is vital for the successful integration of advanced technologies and the future readiness of the workforce.

According to management representatives in most of the establishments investigated, working with advanced equipment did not require specific qualifications or certifications. The interfaces were generally considered user-friendly and only demanded basic digital skills. In the case of the warehouses, although concerns about deskilling may arise, the nature of work as a warehouse operator is typically low-skilled to begin with, and the warehouse workers interviewed did not express worries about deskilling. If anything, the adoption of robotic systems required certain categories of workers, including managers and supervisors, to acquire digital and technical skills related to the operation and maintenance of the robots.

On the manufacturing site, the hiring requirements for shop-floor workers changed with its relocation to a new site, where more advanced robotic systems were in operation. The new requirements include experience working with advanced machinery, a willingness to learn how to operate advanced equipment, problem-solving skills transferable to operating new innovative technologies and soft skills for senior positions that involve managing and supervising employees in an automated work environment.

Similarly, in the Italian hospital, the implementation of the unit dose system required the introduction of new hiring requirements. These were especially necessary in the hospital pharmacy, where there was a demand for technicians well versed in autonomation [10] technologies and advanced equipment.

In previous Eurofound case studies on automation (Eurofound, 2023a), another crucial aspect revealed through interviews with workers in various work settings was some overreliance on technology, which may contribute to a loss of opportunity for job crafting and a loss of skills acquired over time but no longer necessary following the automation of tasks. To some extent, some dependency on the robotic solutions may have also arisen in the manufacturing site investigated in this research, given that operators no longer perform certain manual tasks.

10 Autonomation technologies, also known as 'automation with a human touch' or 'intelligent automation', integrate automatic processes with human intervention to enhance efficiency and quality control. Such technologies are typically applied in manufacturing but they can also be found in other sectors such as healthcare, logistics and customer service, where they enhance operational effectiveness while maintaining a level of human oversight.

Given the extent and variety of demands on staff interacting closely with robotic systems and applications, workers should upskill and engage in lifelong learning throughout their entire professional careers. On-the-job learning, knowledge transfer among colleagues, coaching and mentoring remain crucial to gain critical skills and knowledge due to the complexity of robotic systems.

Working time and work intensity

Previous Eurofound research on the impact of game-changing technologies on work and employment anticipated positive effects of advanced robotics technologies on working time (Eurofound, 2020b). This primarily pertains to the expected reduction in working hours resulting from decreased workload due to the automation of tasks. However, these positive effects could be reversed if the work organisation involves a 24/7 production process and workers are called in at unsocial hours to check or fix failures in the automated processes.

Evidence from the case studies investigated in this research shows that the implementation of robotic technologies did not result in changes to working hours, despite notable time savings achieved through automation. The time saved through automation was redirected towards handling a greater number of orders, particularly in the two warehouses and at the manufacturing site. In other establishments, the time saved was allocated to value-added tasks requiring human-specific capabilities.

In terms of work intensity, the evidence available from the literature and the case studies presents a mixed picture. Drawing on data from the World Robotics Survey and the European Working Conditions Survey (EWCS) for 1995–2005, Anton et al (2021) found that robotisation increased work intensity. This intensity was measured by quantitative aspects of work, such as the pace of work (e.g. determined by machine speed), tight deadlines and time pressure, and the interdependency of work on colleagues, customer demands and production targets. In a similar vein, another German survey-based study found that the introduction of new computer programs and production/processing technologies was associated with increased work intensity (Meyer et al, 2019). In addition, findings from another study, which relied on qualitative interviews with workers in the automotive and machinery manufacturing sector, suggest that Industry 4.0 assembly lines are characterised by high time pressure and an intensified pace of work (Pfeiffer, 2016); the requirement to oversee more than one machine at a time also means that workers must consistently maintain a high level of attentiveness.

By contrast, a 2016 survey with a representative sample of 2,032 German manufacturing and service enterprises found no difference in work intensity, particularly in terms of multitasking (overseeing multiple processes simultaneously), frequent interruptions to work processes and a high pressure to complete work on time, between workplaces using digital technology and those employing traditional mechanical robot automation technology (Arntz et al, 2020).

Mixed evidence also emerged from the case studies investigated in this research regarding work intensity. Based on interviews with warehouse operators, an increase in the number of orders processed did not heighten stress levels or increase work intensity. Operators commonly reported a steady pace of work, which is typically determined by the robotic systems used in such environments. Operators in the Italian warehouse who were interviewed believed that if human operators were deployed for picking and stowing of items instead of robots, they would rush to be more productive than others. However, the mobile robot shelving solution has resulted in more homogeneous productivity rates among workers. Additionally, a maximum of five shelves can queue at a workstation, with potential new ones not permitted to enter the workstation. By contrast, at the manufacturing site, shop-floor workers reported a higher pace of work and working to tight deadlines as a result of automated processes driving increased production goals. However, this was not necessarily perceived negatively by workers; instead, they viewed it as a challenge that encouraged them to develop and enhance their skills.

In the cases of the social robot employed in the Swedish restaurant, the cleaning cobots deployed in the Spanish hospital, and the cobotic technology implemented in the Swedish clinical test laboratory, the technology helped to alleviate workers' daily workload, simplifying their tasks, and, for the analysts in the test laboratory, freeing up time for more analytical tasks. No change in work intensity directly related to the use of the technology was reported in these cases.

In the Italian hospital deploying the unit dose system, staff interviewed observed that any increase in work intensity could not be attributed to the robotic solution itself, which was designed to save time. Instead, they attributed it to management's choice to replace the tasks automated by the robotic system with other more diverse tasks, which were sometimes even more challenging or mentally demanding.

Social environment

There is no conclusive evidence on the impact of advanced robotic applications on social interaction in the workplace. While some scholars argue that increased use of robots may threaten social relations by diminishing the role of workers and causing a sense of loss of control and alienation among them (Smids et al, 2020), studies' findings vary. For instance, a case study on surgical robots indicated a deterioration in interaction within the operating team (Wasen, 2005), but other research in Industry 4.0 workplaces found no significant worsening of social relations (Wurhofer et al, 2015; Arntz et al, 2020; Eurofound, 2021b). If anything, robotic technologies were found to have a positive impact on the social environment, with colleagues responsible for the functioning of the robots helping to overcome the initial scepticism among other workers about the robotic applications (Wurhofer et al, 2015) or the technology increasing interdependencies between departments and roles, thus increasing teamwork and communication (Eurofound, 2021b).

However, previous Eurofound and EU-OSHA case study research points to different outcomes depending on the particular technologies involved and the specific use cases (Eurofound, 2021b; EU-OSHA, 2023a). Other studies emphasise the importance of gaining trust and acceptance among workers for the successful integration of robots into work processes through collaborative and well-communicated implementation processes and human-centric design, leading to positive attitudes towards robots and more efficient human–robot interaction (Bulgheroni et al, 2021).

Similarly, in the establishments investigated, there is no evidence of technology adoption having a negative impact on the social environment at work. However, particularly in the warehouses, the nature of the robotic systems limits social interaction between colleagues, as operators are assigned to individual workstations. In the French warehouse, the workspace was specifically designed to facilitate interaction between colleagues, and operators have the flexibility to rotate between the robot workstation and other tasks (manual picking, control tables, packaging and shipping). This is an example of how a robotic system, although designed so that operators work at individual workstations, can be implemented in a way that minimises adverse effects on the social environment. The benefits of job rotation systems were also highlighted in a previous EU-OSHA case study investigating a cobotic application that automates the sewing of bags in the automotive industry (EU-OSHA, 2023c).

In the Italian warehouse, interviews with staff and management revealed increased interaction between operators and their line managers. With line managers no longer required to manually perform certain tasks, as the robotic system handles task allocation and resource management, they now have time for more frequent and direct engagement with warehouse operators and team leaders. This includes discussions on productivity rates and tasks or actions that could be reviewed, with feedback provided based on the monitoring of work processes.

On the manufacturing site, the adoption of advanced technological solutions improved work relations, facilitating increased communication and collaboration among different departments and roles. Regular exchanges occur between technicians and head or senior operators regarding the efficient operation of advanced equipment and the optimal use of available data. In contrast, at the former site, where manual tasks were prevalent, operators had fewer opportunities to interact with supervisors or colleagues from other departments. Communication among operators during shift changes on the shop floor was identified as an area requiring improvement. Delays in the production line were a significant concern emphasised in interviews. These were primarily attributed to the limited time and interaction between shop-floor operators during shift changes.

In other instances, such as the deployment of cleaning cobots in the Spanish hospital or the introduction of the unit dose system in the Italian hospital, the adoption of technology resulted in more informal exchanges among co-workers regarding the operation of the robots or issues related to their use.

In the Italian hospital, where nurses did not receive formal training, management encouraged informal knowledge exchange. This fostered a stronger sense of community among nurses. The staff interviewed also highlighted the importance of having process champions during the implementation phase. These were ‘educators for nurses’, who, as experienced peers, championed particular practices and traditionally played a crucial role during the initial stages of implementing new technologies in the hospital. In the context of the adoption of the unit dose system, the educators provided continuous support to nurses, motivated them to use the system and collected valuable feedback for its improvement. Previous case study research on pharmacy robots found that the adoption and use of a robotic innovation can reconfigure the boundaries between different occupational groups, with important implications for their work practices, roles and status (Barrett et al, 2012).

The situation differed for pharmacy technicians, who reported a risk of isolation when operating the system. This was attributed to its placement in a small and remote area of the hospital without windows, diminishing their opportunities for interaction with the rest of the team. In such cases, the adoption of a rotation system helped alleviate the risk of isolation for this occupational group. Pharmacy technicians also identified another undesirable aspect of the social environment: the requirement for calling in the on-site technician from the IT provider to conduct routine maintenance or address minor malfunctions that they would otherwise be capable of resolving. This external intervention is sometimes seen as a burden, causing delays in the pharmacy technicians’ daily activities and creating a sense of disempowerment among them.

The introduction of the social robot in the restaurant had a much less favourable impact on the social environment, especially concerning interaction with customers. More experienced front-of-house staff perceived the robot as ‘gimmicky’. They also felt that it somewhat undermined their professional role of focusing on serving customers, interacting with them and advising them on the menu. The robot was seen by more experienced front-of-house staff members as potentially diminishing social interaction with customers.

Occupational safety and health

Physical risks

Advanced robots can handle more hazardous tasks than those that are less advanced, reducing the risk of injuries and minimising the physical strain of manual labour. Industry 4.0 environments typically provide enhanced safety precautions, including the use of smart sensors for detecting and preventing potential risks (Pancardo et al, 2015). Physical safety and ergonomic considerations remain crucial elements of OSH in the context of advanced robotics, particularly those involving close human–robot interaction (EU-OSHA, 2022a; Zorzenon et al, 2022). Ergonomic design considerations, such as the arrangement of workstations and tools, are important in minimising the risk of musculoskeletal disorders and repetitive strain injuries. Empirical studies also indicate that employees in Industry 4.0 work environments report fewer health issues and days of sickness leave than those in traditional work environments (Arntz et al, 2020).

These findings were also apparent in the case studies investigated in this research: robotic systems and applications enhanced the health and safety of workers. This improvement was primarily achieved by reducing the risks of accidents and injuries, making work less strenuous and physically demanding.

At the manufacturing site, the higher degree of automation compared with the less automated previous factory resulted in improved safety for shop-floor workers. This improvement is evidenced by the elimination of injuries associated with lifting heavy objects and a reduction in overall fatigue. Safety features were built into the technology both at the manufacturing site and in the two warehouses, and each component of the system was equipped with a redundant security system. The warehouse workers interviewed observed that while personnel cannot directly control certain processes on traditional sites, machines in robotic warehouses can be promptly stopped and alarms activated in the event of any issues.

In both warehouses investigated, the use of robots also reduced the need for workers to cover long distances and minimised physical movements, thereby significantly decreasing the likelihood of injuries. Task rotation also helps to lower the risk of musculoskeletal disorders, as the continuous repetition of the same movements over time can be detrimental. However, the robotic solution still requires operators to pick up items or boxes from the shelves and place them in the trays. According to warehouse workers interviewed, these repetitive movements can lead to arm pain, especially if performed too quickly or if they involve carrying heavy boxes.

Furthermore, continuous monitoring ensures the safe operation of robotic systems. In the French warehouse, this monitoring is conducted remotely by an external provider, while the Italian warehouse has a specialised team overseeing the safe use of equipment and compliance with safety standards, with another layer of control being provided by line managers. Despite workers acknowledging that occupational hazards cannot be entirely eradicated from warehouses, they argue that such risks are less frequent in robotic warehouses than traditional ones.

In other establishments investigated, the robotic technologies were viewed positively by staff, increasing physical safety and making work less physically demanding. In the case of the cleaning cobots, cleaning staff reported reduced physical strain and lower exposure to ergonomic risks (through repetitive movements, prolonged standing or walking), thus alleviating commonly reported ailments. However, physical labour is still involved in cleaning tasks not handled by the cobots. The use of cobots also reduced the risk of accidents, as no cleaners were transporting cleaning trolleys, minimising the chances of collisions and accidents. Albeit applied in a different work setting, the cobotic technology implemented in the Swedish test laboratory also alleviated wrist and shoulder pain (associated with the repetitive movements involved in handling test tubes) among analysts. Staff are routinely exposed to a range of repetitive movements when unpacking, registering, sorting and pre-processing samples, of which there are thousands. Such repetitive movements can result in injuries and an increase in sick leave. Positive views were also expressed by front-of-house staff in the restaurant using the social robot, as it alleviated some of the physical workload and made their job more manageable. For some staff, the benefits were most apparent to them on days off, especially following a busy shift the day or evening before.

In the case of the unit dose system deployed in the Italian hospital, concerns were expressed by pharmacy technicians regarding the ergonomics of the machines for preparing and dispensing medication, which was largely due to a lack of consultation with affected staff during the design process.

Previous research suggests that, despite the safety precautions implemented, new robotic technologies may introduce additional health and safety requirements and physical hazards (EU-OSHA, 2022a, 2022d). These risks could arise from robot malfunctions, communication breakdowns, human errors, cybersecurity issues or organisational weaknesses (EU-OSHA, 2022a, 2022d; Leso et al, 2018). Factors such as the distance between the operator and the robot, obstacles, the robot's speed, the psychological or physiological state of the operator and ergonomic solutions must be carefully considered in safety concepts and the redesign of work processes (EU-OSHA, 2022a; Leso et al, 2018). Aspects of technology reliability, including perceived safety, were identified in prior research as linked to trust in human–robot collaboration. These factors influence workers' willingness to collaborate with robots, affecting their acceptance of and satisfaction with them and thereby connecting with aspects of their psychosocial well-being (Charalambous et al, 2015; Charles et al, 2015; Palmarini et al, 2018).

Psychosocial risks

Physical safety is a prerequisite for safe human–robot interaction but it is not the only consideration. In addition to physical risks, close interaction between humans and robots may give rise to psychosocial risks, which can have implications for workers' well-being and mental health. Lasota et al (2014) argue that there are two components of safe human–robot interaction – physical safety and psychological safety. Psychological aspects of safety include the context in which the robot is used, comfort with robot use, experience and familiarity with robots, trust in robots, the sense of control over interaction with robots, and transparent and predictable robot actions (Akalin et al, 2023).

Research suggests that the introduction of advanced robots in the workplace can result in anxiety, stemming from a lack of knowledge about how to interact with robots, fear of being physically harmed or fear of job substitution (Smith et al, 2020). A review of previous studies on human–robot interaction revealed that the main barriers to robot adoption include concerns around (perceived) safety and usability, apprehension about being replaced by robots and a sense of forced cooperation or perceived 'non-cooperation', as individuals must adjust to the robot's behaviour and relinquish control to the machine (Baltrusch et al, 2022). Another study, drawing on semi-structured interviews with 36 employees in five different manufacturing companies in Germany, identified stressors associated with human–machine interaction (Körner et al, 2018). These included technical issues, poor usability, diminished situational awareness and increased qualification requirements for employees. Notably, technical problems such as breakdowns or slowdowns emerged as a significant stressor, particularly when employees lacked the requisite skills to address such issues. These, in turn, impeded workflows, introducing additional time pressures.

Some of these concerns were voiced by cleaning staff in the case of the cleaning cobots deployed in the Spanish hospital, as well as by pharmacy technicians and nurses utilising the unit dose system in the Italian hospital. In the case of the cleaning cobots, staff initially expressed apprehension about operating expensive equipment that they perceived as delicate, coupled with being responsible for its maintenance. However, these fears gradually diminished over time as they became more familiar with the technology through regular usage.

In the Italian hospital, the introduction of the robotic system caused some stress and anxiety among pharmacy technicians and nurses, particularly during the initial stages of implementation. For pharmacy technicians, uncertainties related to the stock of medicines to be uploaded onto the system and adapting to the changed workspace contributed to the stress. They felt the pressure and the responsibility to not fail in the adoption of this technology, as any machines' malfunction could delay or generate a mistake in the production of the patients' therapies. Interviews revealed uncertainty regarding accountability in the event of a mistake during medicine dispensation, making it unclear whether responsibility lies with the robotic system or the human operators. For nurses, the anxiety stemmed from a lack of familiarity with the new system, exacerbated by a lack of formal training and the co-existence of another system for medicine dispensation. Over time, they came to value the unit dose system, particularly for reducing the risk of human error in producing and dispensing medical therapies and ultimately increasing the safety of both patients and workers.

At the manufacturing site, the pace of work, largely dictated by machines, somewhat intensified to meet tight deadlines associated with achieving higher production goals (expected because of a higher level of automation) and frequent delays in the production line. These delays were primarily attributed to technical difficulties encountered during shifts and a lack of efficient communication between workers on different shifts in a pressurised work environment. However, the productivity targets could be adjusted to account for the difficulties encountered. In addition, shop-floor workers are not required to work extra hours if they do not meet the set production goals, thereby eliminating another potential source of stress. According to the interviewees, more comprehensive training provision could have better prepared them to operate the advanced equipment more efficiently and avoid some of the technical issues occasionally experienced.

Other concerns expressed by workers in some establishments related to greater potential for job replacement due to automation. These concerns were particularly pronounced in the initial stages of technology implementation, when uncertainties were higher. Such apprehension gradually diminished as workers became more familiar with the technologies and realised that workers were still needed for other tasks. In addition, there is a growing awareness among staff that a higher level of automation is inevitable, necessitating efforts and some acceptance on their part to adapt.

More specific to warehousing activities, insight gleaned from a study based on interviews with 34 warehouse workers and 33 front-line supervisors in China, France, Spain, the United Kingdom and the United States (US) revealed a mix of concerns and hopes among workers interviewed as regards automation (Lui et al, 2022), which may influence workers' well-being and job satisfaction. This sector is frequently scrutinised for its poor working conditions, often exemplified in the media by practices in Amazon's fulfilment centres. While the workers interviewed did express apprehension about potential job losses, inadequate training resources and challenges posed by downtime or errors resulting from technology malfunctions, they also voiced optimism, anticipating that automation would increase safety and boost productivity, and that it has the potential to increase the overall quality of their work.

An important human factor in human–robot interaction is the decision process for task allocation between humans and machines, which is crucial for functioning cooperation between humans and robots and vital for psychological well-being (Tausch et al, 2020). Research highlights the important role of autonomy in task allocation and process control, emphasising its impact on the mental well-being of workers. However, autonomy in both task allocation and process control may introduce a higher demand for mental effort, required to make informed allocation decisions (Tausch et al, 2020). Assistance systems can play a supportive role, as long as they are not overly complex (Onnasch et al, 2014).

Furthermore, if workers do not have access to the information that led to the allocation of their tasks, or if their new task allocation decreases their sense of task fulfilment or completeness, this will have a negative impact on their mental health (Hacker and Sachse, 2014). Lack of prior notification about the robot's speed also contributes to increasing cognitive load, highlighting the importance of informing operators about movement characteristics to prevent cognitive overload. Increasing the predictability of robot behaviour is essential for mitigating cognitive strain, and incorporating visual input with additional information on robot parameters has the potential to enhance human–robot collaboration (Baltrusch et al, 2022).

The reviewed literature also suggests that human–robot interaction can either heighten cognitive demands, which are closely associated with stress and perceived work pressure, or alleviate cognitive load, potentially causing reduced attention and elevating the risk of errors, posing safety hazards (Baltrusch et al, 2022). This highlights the importance of identifying and adjusting the optimal cognitive workload to maintain job quality when introducing a robot.

In the two warehouses investigated, the robotic solution contributed to reduced mental strain and cognitive load. This was credited to the straightforward process of following on-screen instructions and the assistance provided by the laser spotlight indicating the items to pick or store and where to place them. This has reportedly also resulted in a decreased risk of errors related to item type and quantity compared with manual picking.

Reduced mental load was also reported by analysts interviewed in relation to the use of cobotic technology in the Swedish test laboratory. The technology had a positive impact on their mental well-being, relieving them of some of the stress they experienced, especially during peak periods when the laboratory received large batches of test tubes to process. From the point of view of human–robot interaction, a notable aspect of this application of the technology is that collaboration with the robot was not imposed, and analysts did not feel constrained or dependent on the robot. In addition, the training and support received from qualified peers were acknowledged as crucial factors contributing to trust in and acceptance of the technology.

In contrast, at the manufacturing site, the use of the automated systems heightened job complexity and mental load for shop-floor operators, who are tasked with ensuring the efficient operation of advanced equipment. The growing demands associated with operating robotic systems and supervising automated processes, coupled with occasional technical challenges faced by operators and communication difficulties during shift changes, have the potential to worsen the psychological well-being of workers.

Earnings and career prospects

In the establishments investigated, the increase in productivity and efficiency following adoption of the technology did not result in salary increases or career advancement for affected workers. Neither worker representatives nor workers in any of the establishments raised the issue of salary adjustments with the management. The technological change was presented to workers as a way of improving their work, with an implicit understanding that salary hikes were not required.

The most notable increase in productivity and annual turnover was apparent in the case of the Lithuanian manufacturing site, following its relocation to a highly automated environment. This did not translate into higher wages for shop-floor workers, who were most affected by the adoption of the robotic technology. Nonetheless, workers at the site received financial incentives (ranging from 10% to 50% of their monthly salary) for making suggestions to management to enhance the system or for identifying and reporting any issues related to health and safety or affecting the productivity of their assigned production lines.

In the case of the Italian hospital, the adoption of the unit dose system increased efficiency in the preparation and collation of therapies. However, once again, this greater efficiency did not have a direct positive spillover effect on salaries. Besides, feedback from the focus group with employees indicated that the time saved in therapy production did not translate into additional time for providing care to the same number of patients. Instead, the changes appeared to contribute to increasing the workload of each nurse.

While efficiency gains benefit organisations, they do not necessarily result in improved career prospects or salary adjustments. The reasons for these dynamics can be multifaceted and dependent on factors such as management decisions, employees' expectations and the specific nature of the tasks involved.

Collective bargaining, especially at company level, plays an important role in fostering the more equitable distribution of gains derived from automation (Eurofound, 2023b). In some EU Member States, collective bargaining provides for wage-setting, taking into account economic factors such as productivity levels (Eurofound, 2023b). As highlighted in an earlier Eurofound review, despite employers and trade unions prioritising wage-setting and working hours in their negotiation agendas, they do not consistently connect these with technological advancements (Eurofound, 2021d).

Impacts on employment

Job displacement by machines has been a hot topic for some time in policy and academic debates. However, estimates vary widely across studies. These range from an assessment that only 9% of jobs are 'automatable' according to the study conducted by Arntz et al (2016) for the Organisation for Economic Co-operation and Development (OECD) to the assertion that 47% of US workers could be affected according to the pioneering study by Frey and Osborne (2013).

Based on the assumption that the scale of employment effects is related to robot adoption rates, contingent on the costs of technology investments, a Eurofound foresight study (2019b) investigated three distinct automation scenarios. The first scenario assumes high costs and hence the slow adoption of technology, the second scenario assumes low costs with the quick adoption of technology and the third scenario envisages low costs with reduced working hours and no reduction in pay. Compared with a baseline scenario with no acceleration in automation, the expected job loss from automation by 2030 is higher in the EU (10% in the high-cost scenario and 16% in the first low-cost scenario) than in the US (9% and 14%, respectively).

In spite of such predictions, there is no evidence of job redundancies resulting from the adoption of technology in the case studies examined, both in this research and in prior Eurofound research on robotic technologies (Eurofound, 2023a). These findings are consistent with previous Joint Research Centre case study research in the services sector showing that the adoption of automation technologies has not led to job displacement (Cirillo et al, 2022). In certain instances, such as in the logistics sector, the execution of specific tasks has been reconfigured. With a focus on AI adoption, OECD case studies also found that employment levels have remained steady, with redundancies being rare (Milanez, 2023). This could be because the technologies were not sufficiently advanced or because their introduction was aimed at augmenting work rather than cutting labour costs.

Productivity growth as a result of automation – and particularly collaborative systems – should translate into good-quality jobs.

In some of the case studies investigated in this research, technology adoption instead gave rise to the creation of new technical jobs, as seen in the Italian warehouse, where additional, though not entirely novel, roles such as hardware engineers, software engineers and safety experts have become essential for the correct functioning and maintenance of the robotic system.

In addition, in the Italian hospital, the implementation of the unit dose system required the recruitment of a biomedical technician accustomed to operating an autonomation system and machines in a biomedical laboratory. According to the HR manager interviewed and the director of the hospital pharmacy, the successful implementation of this transformative technology relies on pharmacy technicians who are well versed in the use of automation.

In other case studies of cobotic applications within this research, one important objective of technology adoption was to relieve workers from tedious, repetitive or physically demanding tasks, rather than replace workers altogether. The primary goal of cobotic technologies contradicts the notion of substituting humans, as cobots are specifically designed for close interaction and collaboration with humans, thereby complementing humans' abilities. When deployed in a genuinely collaborative manner, cobotic applications have the potential not only to generate but also to preserve jobs.

However, cobots tend to work at a low level of collaboration with workers or without any physical contact with them, often for automation purposes akin to traditional industrial robots (EPRS, 2023). Such uses are more conducive to the substitution of humans rather than fostering meaningful collaboration with them. In a previous Eurofound case study investigating cobotic technology in a Finnish medical device factory (Eurofound, 2023a), the first cobots deployed in the establishment were placed within fenced areas, operating at a safe distance from workers; this resulted from the insufficient consideration of human factors during the design and planning stages. This proved to be a learning experience, contributing to the subsequent deployment of more collaborative cobots, leveraging their inherent benefits.

Regarding job growth in automated environments, Acemoglu and Restrepo (2019) argue that despite firms expanding their operations and creating new jobs using robotic installations, the aggregate demand for labour remains stagnant. They argue that the acceleration of automation, especially in manufacturing, has resulted in the deceleration of the creation of new tasks, which fall short of compensating for the jobs lost to automation.

Concerns about potential future job losses persisted among workers in some of the establishments investigated, although not necessarily in those adopting the most impactful systems. In the establishments where such concerns were raised, workers' apprehensions diminished after the technology was deployed as they became familiar with the robotic applications and perceived themselves as essential for operating the equipment.

Although management reassured workers of their job security in these establishments, companies' plans often indicate a willingness to scale up automation in the near future, hinting at potential redundancies.

For instance, in the case of the cleaning cobots, the company anticipates the technology becoming more sophisticated, allowing the cobots to operate independently of human operators. The company is closely monitoring developments in cobotic technologies for cleaning services, with a long-term vision of adopting cobots that autonomously perform an increasing number of cleaning tasks.

Similarly, in the case of the restaurant, the management views the robot as a valuable asset. Due to challenges in recruiting and retaining trained staff, there are plans to extend the use of robots to other restaurants. This could potentially influence employment levels and staff profiles in the future.

Previous case studies from Eurofound on automation indicate that when a substantial portion of tasks within a job are automated, workers are often relocated to a different area within the firm rather than being made redundant (Eurofound, 2023a). This was evident, for instance, in a previous case study examining automation implemented by a German container terminal operator. Workers who were relieved of manual tasks on the terminal ground were moved to a control room where they performed supervisory and controlling tasks. However, the expectation is that some jobs may ultimately be eliminated in the longer term, as fewer workers will be needed in the control room to operate the machinery remotely. Due to the presence of a strong trade union (ver.di) that negotiated a company-level collective agreement on innovation and job protection, there have been no redundancies (as yet) at the terminal.

Summary

- The adoption of robotic technologies in the establishments investigated resulted primarily in the automation of manual and routine tasks, and did not affect entire job profiles. The most significant changes to the nature of tasks were observed in establishments that adopted more complex and interconnected robotic systems.
- In establishments with complex robotic systems, the adoption of the technology necessitated the redesign of the workspace and substantial adjustments to existing workflows, with a primary focus on safety and ergonomic considerations. In these establishments, the robotic systems rely on the real-time collection and processing of large amounts of data about workers' activities. Although it is technically feasible, the managers interviewed denied monitoring the performance of individual workers. Monitoring is typically carried out at the level of the team or production line, or the establishment.
- With close human–robot interaction and in highly standardised work environments, robotic systems may further restrict their operators' freedom to determine how to perform their jobs. In cases where the robotic technology is a discretionary tool for staff, which complements their work, no changes to job discretion were observed.
- No evidence of deskilling was found in the establishments investigated; if anything, workers operating or using robotic systems reported an improvement in their digital competencies and skills, primarily acquired on the job rather than through formal training.

- The implementation of robotic technologies in the establishments investigated did not result in changes to working hours; instead, the time saved was redirected towards handling an increased number of orders or allocated to value-added tasks. Work intensity varied across establishments and was often determined by management decisions or the suboptimal organisation of work, rather than the technology itself.
- The case studies point to diverse impacts of robotic solutions on the social environment. Some robotic systems – such as those implemented in warehouses – tend to restrict social interaction. However, the positivity or negativity of the impact is contingent on specific applications, and, crucially, on design and management decisions.
- The advanced robotic systems and applications examined were designed with embedded safety precautions and ergonomic considerations. Overall, they had a positive impact on the physical environment, by performing tasks that are repetitive or physically demanding for workers, thereby reducing physical strain and lowering the risk of injuries or accidents. Some robotic solutions were also intended to streamline and simplify tasks and in doing so reduce workers' mental load. However, in some instances, mental load increased due to additional demands on workers operating the advanced equipment.
- With regard to earnings and career prospects, the increased productivity and efficiency resulting from technology adoption across all establishments investigated did not translate into salary increases or tangible career advancement for affected workers.
- There is no evidence of redundancies resulting from technological change in the establishments investigated, nor are there examples of entirely new occupations being created due to the introduction of the new robotic systems or applications. However, concerns about future job losses persist among workers in some of the establishments investigated. Despite management's assurances, companies' plans suggest a trend towards increased automation, potentially leading to redundancies in the not-too-distant future.

4 Conclusions

Businesses adopt advanced robotic technologies for various purposes, driven by both internal factors and labour market conditions (particularly high labour costs or labour shortages). Evidence from the case studies reviewed in this research indicates that the primary motivation for adopting advanced robotic systems and applications is to increase competitiveness and productivity, with improvements in job quality considered a secondary motivation. Motivations for the introduction of robotic technologies have important implications for interaction between humans and robots, influencing design decisions and technology implementation.

It is important that robotic solutions are not only fit for purpose but also human-centric – that is, designed with a deep understanding of the tasks they will perform and the humans they will interact with. By integrating human-centric principles into robotic design and development or customisation, organisations can rely on technological solutions that increase productivity, efficiency and overall well-being in the workplace. This also applies to algorithmic management systems, which are increasingly integrated into enterprise-level software and robotic solutions in ways that may not be immediately apparent to both workers and managers.

Workers interviewed for the case studies acknowledged that the primary advantage of automation was increased physical safety. However, they also recognised that the introduction of robotic technologies, despite reducing physical strain and automating physically taxing tasks, does not eliminate all challenges. Workers must still perform a great deal of physically demanding tasks, and they face additional demands to operate the new machineries safely and efficiently. Given these considerations, there is a case to be made for emphasising human-centric design, which is pertinent not only for AI-powered technologies but for all advanced robotic applications involving close interaction with workers. The future plans of establishments adopting advanced robotics reveal that they have clear intentions to continue the current automation trajectory and scale up their efforts by integrating AI technologies as an additional layer in their digital infrastructure. By prioritising human factors, human-centric design ensures that robotic systems and applications align with workers' expectations, fostering greater acceptance of the technology, confidence in the technology and adaptability to changing roles or tasks. It also enhances workers' health and safety in a broader sense, considering cognitive and psychosocial aspects of human–robot interaction.

Eurofound research consistently emphasises the crucial role of social dialogue in securing better outcomes from technology adoption in the dual interest of promoting workers' well-being and increasing productivity and efficiency (Eurofound, 2021b, 2023a). However, both previous Eurofound case studies and those investigated in this research indicated that introducing technologies is typically a top-down decision; workers' involvement is often limited to being informed about the rationale of introducing the technology prior to its rollout in the workplace, representing a more passive form of involvement.

A lack of worker involvement – often extended to risk assessments (when conducted) and piloting – limits the incorporation of human factors in the design of the robotic systems or applications deployed in the establishments. This may lead to the omission of crucial information necessary to increase the human centricity of robotic technologies. A participatory approach to technology design and adoption has other benefits; it instils a sense of co-ownership and fosters greater acceptance of and trust in the newly introduced technologies and changes to work routines.

The operational set-up of traditional robots, especially in production systems where robots are traditionally enclosed in cages and positioned at a safe distance from workers, contributes to the inherent mistrust workers feel about being in close proximity to robots. A human-centric approach to designing or customising robotic solutions, where workers actively contribute to such processes, can help mitigate the psychological predisposition of the workforce to anticipate segregation and harbour mistrust when working alongside robots.

Bearing out the routine-biased technological change hypothesis, the implementation of robotic technologies in the establishments examined predominantly automated repetitive and manual tasks. This resulted in reduced physical strain and freed up time for additional, higher-value tasks. There remains, however, a substantial number of tasks for affected workers to perform, mitigating any immediate threats to existing jobs. Moreover, new tasks, such as monitoring, supervision, maintenance or exception handling, compensate for the automation of certain manual tasks. The evidence reviewed also suggests that automated processes – including in highly automated environments – still rely on human skills, including analytical thinking, problem-solving, project management, collaboration and communication skills. Collaboration and communication skills are particularly crucial due to the increased interdependencies between departments and roles brought about by robotic technologies, as observed in some case studies.

The case study evidence also indicates that training provision is frequently limited in both scope and duration. Representatives of management interviewed during the research often considered the machines easy to operate, with no specific skills or competencies required from workers. For instance, in automated warehouses, individuals hired as pickers and stowers may need little or no technical expertise to do their job, as they are guided by the systems regarding the work to be done and the exact sequence of tasks. In such cases, training provision could seek not only to ensure safe interaction with the robotic systems but also to increase workers' ability to address technical issues with automated tools when they arise. This would provide them with opportunities for career growth, allowing them to move up the ranks into management positions or more technical roles. This type of training provision can be considered a form of reskilling and upskilling.

Although there was no evidence of redundancies due to automation, concerns about future job losses persisted among workers in some establishments, particularly in the initial stages of technology implementation. These concerns were often addressed by management, who reassured staff that the technologies were not intended to cut labour costs; yet future plans in some cases contradict this, indicating an intention to automate as many tasks as possible. This is consistent with the incremental approach to digitalisation observed in previous Eurofound case study research on automation and digitisation (Eurofound, 2021b, 2023a). According to management interviews, the upscaling of automation efforts largely depends on the costs of the technologies and the availability of proven business cases. Workers expressed other concerns in interviews, for example related to uncertainties, a lack of confidence in the technology and an initial uneasiness in working with robots. Over time, as workers became more familiar with the robotic solutions implemented in their work, these concerns diminished.

While advanced robotics contributes to productivity and efficiency gains, these improvements do not necessarily lead to career advancement, job growth or increased salaries for affected workers, at least in the short term. The improvements made in automated tools – after their rollout in the workplace – often rely on workers' feedback as to what works and what does not, based on their experience of using the technologies, as well as insight gleaned from the vast amount of data continuously collected and processed about work processes. A case can be made for workers to be recognised for producing knowledge and to benefit from the vast amounts of data they continuously generate by doing their work. These data are typically leveraged to refine automated processes, potentially leading to the replacement of their roles in the not-too-distant future.

Furthermore, contrary to initial positive expectations that advanced robotic technologies would result in shorter working hours due to a reduced workload, the case studies suggest that the time saved through automation is usually redirected towards other tasks. These tasks require human intervention and, in some instances, are more cognitively demanding. However, these outcomes result from organisational factors and management choices, rather than being direct effects of technology design and adoption.

Policy pointers

- Consistently with previous Eurofound case studies, the research shows that organisations take a conservative stance to technology adoption, relying on proven business cases. This cautious approach is reflected in the relatively stable share of enterprises in the EU using robots. This highlights the importance of disseminating good practices grounded in valid business cases and raising awareness of the opportunities that automation technologies can offer to workers and firms, especially when guided by human-centric design principles. Policymaking plays a crucial role in promoting collaboration to share best practices, exchange knowledge and establish global standards for the human-centric design of advanced robotics. Public awareness campaigns should draw attention to the benefits and risks of advanced robotics in workplaces, emphasising the importance of prioritising the creation of good-quality jobs in implementing technological advancements.
- Policymakers have a responsibility to ensure that technological advancements align with human values, promoting a fair and just society and serving a good purpose. The human-centric design of technologies could be encouraged through public incentives for research and development. Robotic applications designed with a human-centric approach can also contribute significantly to generating sustainable solutions to demographic challenges, notably the declining workforce resulting from an ageing population. With a shrinking labour force, robots can fill gaps in industries facing labour shortages, such as healthcare, manufacturing and agriculture. Cobots in particular can work alongside humans in several work settings, increasing productivity and efficiency while minimising physical strain for workers.

- Public–private partnerships are instrumental in advancing a human-centric approach to the design, development and use of technologies, by pooling resources, accessing specialised expertise, facilitating capacity building and increasing public trust. Notable examples of such collaborations can be found in initiatives within the EU's research and innovation programme, Horizon Europe (2021–2027). It is imperative that these partnerships undergo thorough evaluation and assessment to drive continuous improvements and facilitate learning and knowledge sharing.
- The evidence suggests that advanced robotics has the potential to have a positive impact on workers, by increasing their physical safety and easing their workload. However, it is not without its downsides, which often arise from organisational weaknesses or short-sighted management decisions. One area where employers face difficulties is in effectively implementing training programmes. As organisations scale up their automation efforts, there is a need to move beyond a training approach that entails only providing simple instructions or demonstrating how to operate robotic machines. Training should be an integral part of sound change management, aimed at improving workers' safety and confidence when operating advanced equipment, increasing their resilience and adaptability to new or changing roles, and opening up paths for career growth. It is crucial to involve works councils and trade unions in the design and implementation of upskilling or reskilling programmes from the outset. If workers and their representatives feel part of the conversation and understand the rationale for such programmes, they are more likely to have a positive view of and actively engage in them. From a policymaking perspective, continued efforts should be directed towards supporting initiatives to implement education and training programmes that focus on developing skills relevant to human–robot collaboration, improving workers' digital literacy and increasing their adaptability and resilience in the face of automation.
- The evidence suggests that companies do not sufficiently engage workers in the design or adaptation/customisation of robotic systems or applications, missing important opportunities to better support them, enhance the quality of their work and prevent OSH risks. Establishments lacking in-house capabilities to design and develop robotic systems often resort to deploying off-the-shelf solutions created by third-party developers. This practice can present substantial challenges for management, hindering managers' ability to fully understand or control these systems. As evidenced by the case studies examined, all robotic systems, whether procured externally or developed in-house, need some adaptation or tailoring to their operational environment. This adaptation process should be deliberate, with sufficient time allocated to incorporating feedback from workers. Ensuring that human factors are integrated into the customisation of robotic systems or applications is essential for their successful deployment in the workplace. Encouraging policies that ensure the active involvement of workers in the design or customisation, testing and implementation of robotic technologies is essential to foster a sense of ownership and trust among workers. The social partners play a role in shaping policies that prioritise human-centric values and participatory approaches to technology design and implementation in workplaces.
- A narrative evoking 'doomsday scenarios' of job losses due to automation has dominated the policy and public debate on the automation of work for some time. In recent times, the labour market has witnessed persistent labour shortages in several countries. The policy focus should pivot away from an overemphasis on anticipated job losses due to automation. Instead, the priority is to ensure good job quality outcomes, with human centricity being a key approach. This entails rethinking the role of technologies in the workplace. Instead of viewing them merely as tools to replace human tasks, they should be thought of as complementing humans' capabilities. Human-centric technologies, whether AI-powered or not, necessitate the active involvement of workers throughout their life cycle. This paradigm shift entails treating workers as co-creators of technological solutions, and sources of innovation, rather than costs to be cut. A first step in this direction involves developing and disseminating guidelines and standards for the ethical and human-centric design and deployment of advanced robotics, with an emphasis not only on physical safety but also on broader aspects of job quality and human factors. The concept of human centricity, which revolves around workers' active involvement and participation, is equally applicable to the adaptation or customisation of off-the-shelf robotic systems or applications adopted in establishments that lack in-house capabilities to design and develop their own robotic solutions.
- While traditional risk assessment tools are valuable, the rapid evolution of advanced robotic

technologies may pose challenges that require the continuous adaptation and improvement of existing tools. A significant issue lies in the oversight of digital technologies, often excluded from risk assessments. Furthermore, advanced robotic technologies – often involving interconnected systems and requiring collaboration between robots and humans – can introduce novel risks that necessitate the development of tailored tools to address the inherent challenges of human–robot interaction. Collaboration between experts in robotics, safety professionals, policymakers and industry stakeholders is essential to develop and refine tools that address the unique challenges posed by new robotic technologies.

- An unresolved issue is the extent to which productivity gains from automation should or could be shared in an equitable way with workers. Productivity gains have long been a topic of controversy, given the complexity of the concept itself and the multitude of methods used to measure them. With the advent of automation, this debate has only intensified. While the literature has extensively discussed the impact of technology on productivity, the evidence is inconclusive, suggesting a need to re-evaluate measurement methods. New approaches may be necessary to capture the full extent of changes in productivity in the digital age. Eurofound aims to contribute to this policy debate by conducting research, planned for 2026, intended to review indicators used to measure productivity and explore the complex relationship between productivity and wages.

References

All Eurofound publications are available at www.eurofound.europa.eu

Acemoglu, D. and Restrepo, P. (2018), 'Modeling automation', *AEA Papers and Proceedings*, Vol. 108, pp. 48–53.

Acemoglu, D. and Restrepo, P. (2019), 'Automation and new tasks: How technology displaces and reinstates labor', *Journal of Economic Perspectives,* Vol. 33, No. 2, pp. 3–30.

Adriaensen, A., Costantino, F., Di Gravio, G. and Patriarca, R. (2022), 'Teaming with industrial cobots: A socio-technical perspective on safety analysis', *Human Factors and Ergonomics in Manufacturing and Service Industries*, Vol. 32, No. 2, pp. 173–198.

Akalin, N., Kiselev, A., Kristoffersson, A. and Loutfi, A. (2023), 'A taxonomy of factors influencing perceived safety in human–robot interaction', *International Journal of Social Robotics*, Vol. 15, pp. 1993–2004.

Andelfinger, V. P. and Hänisch, T. (2017), *Industrie 4.0: Wie cyber-physische Systeme die Arbeitswelt verändern*, Springer Gabler, Wiesbaden, Germany.

Anton, J. I., Fernández-Macías, E. and Winter-Ebmer, R. (2021), *Does robotization affect job quality? Evidence from European regional labour markets*, JRC Working Papers Series on Labour, Education and Technology No. 2021-05, European Commission, Seville.

Arntz, M., Gregory, T. and Zierahn, U. (2016), *The risk of automation for jobs in OECD countries: A comparative analysis*, OECD Social, Employment and Migration Working Papers No. 189, OECD Publishing, Paris.

Arntz, M., Dengler, K., Dorau, R., Gregory, T., Hartwig, M., Helmrich, R. et al (2020), *Digitalisierung und Wandel der Beschäftigung (DiWaBe): Eine Datengrundlage für die interdisziplinäre Sozialpolitikforschung – Datenreport und Forschungspotenzial*, Dokumentation 20-02, Mannheim, Germany.

Autor, D. H., Levy, F. and Murnane, R. J. (2003), 'The skill content of recent technological change: An empirical exploration', *Quarterly Journal of Economics*, Vol. 118, No. 4, pp. 1279–1334.

Baiocco, S., Fernández-Macías, E., Rani, U. and Pesole, A. (2022), *The algorithmic management of work and its implications in different contexts*, European Commission, Seville, JRC129749.

Baltrusch, S. J., Krause, F., de Vries, A. W., van Dijk, W. and de Looze, M. P. (2022), 'What about the human in human robot collaboration? A literature review on HRC's effects on aspects of job quality', *Ergonomics*, Vol. 65, No. 5, pp. 719–740.

Bandyopadhyay, S., Baticulon, R. E., Kadhum, M., Alser, M., Ojuka, D. K., Badereddin, Y. et al (2020), 'Infection and mortality of healthcare workers worldwide from COVID-19: A systematic review', *BMJ Global Health*, Vol. 5, No. 12, e003097.

Barrett, M. I., Oborn, E., Orlikowski, W. J. and Yates, J. (2012), 'Reconfiguring boundary relations: Robotic innovations in pharmacy work', *Organisation Science*, Vol. 23, pp. 1448–1466.

Bragança, S., Costa, E., Castellucci, I. and Arezes, P. M. (2019), 'A brief overview of the use of collaborative robots in Industry 4.0: Human role and safety', in Arezes, P. M., Baptista, J. S., Barroso, M. P., Carneiro, P., Cordeiro, P., Costa, N. et al (eds.), *Occupational and environmental safety and health*, Studies in Systems, Decision and Control, Vol. 202, Springer, Cham, Switzerland.

Bulgheroni, M., Tageo, V., Badone, G. and Carsello, A. (2021), *How the digital transformation can put humans at the centre of robotics and automation – Collaboration between humans and machines for better quality products and services*, European Economic and Social Committee, Brussels.

Charalambous, G., Fletcher, S. R. and Webb, P. (2015), 'Identifying the key organisational human factors for introducing human–robot collaboration in industry: An exploratory study', *International Journal of Advanced Manufacturing Technology*, Vol. 81, pp. 2143–2155.

Charalambous, G., Fletcher, S. and Webb, P. (2016), 'The development of a scale to evaluate trust in industrial human–robot collaboration', *International Journal of Social Robotics*, Vol. 8, No. 2, pp. 193–209.

Charles, R. L., Charalambous, G. and Fletcher, S. R. (2015), 'Your new colleague is a robot. Is that ok?' in Sharples, S., Shorrock, S. and Waterson, P. (eds.), *Contemporary ergonomics and human factors 2015*, CRC Press, Boca Raton, Florida, pp. 307–311.

Cirillo, V., Rinaldini, M., Virgillito, M. E., Divella, M., Manicardi, C., Massimo, F. et al (2022), *Case studies of automation in services – A workplace analysis on logistics, cleaning and health sectors in Italy*, Publications Office of the European Union, Luxembourg.

EPRS (European Parliamentary Research Service) (2023), *Analysis exploring risks and opportunities linked to the use of collaborative industrial robots in Europe*, Brussels.

EU-OSHA (European Agency for Safety and Health at Work) (2015), *A review on the future of work: Robotics*, discussion paper, Publications Office of the European Union, Luxembourg.

EU-OSHA (2018), *Foresight on new and emerging occupational safety and health risks associated with digitalisation by 2025*, Publications Office of the European Union, Luxembourg.

EU-OSHA (2020), *Musculoskeletal disorders in the healthcare sector*, discussion paper, Publications Office of the European Union, Luxembourg.

EU-OSHA (2022a), *Advanced robotics and automation: Implications for occupational safety and health*, report, Publications Office of the European Union, Luxembourg.

EU-OSHA (2022b), *Advanced robotics and automation: What are the risks and opportunities for occupational safety and health?* policy brief, Publications Office of the European Union, Luxembourg.

EU-OSHA (2022c), *OSH Pulse – Occupational safety and health in post-pandemic workplaces*, Publications Office of the European Union, Luxembourg.

EU-OSHA (2022d), *Advanced robotics and automation: What is it and what is the impact on workers?* policy brief, Publications Office of the European Union, Luxembourg.

EU-OSHA (2023a), *Advanced robotic automation: Comparative case study report*, Publications Office of the European Union, Luxembourg.

EU-OSHA (2023b), *Collaborative robot lifting parts in an automotive and industrial supplier*, case study, Publications Office of the European Union, Luxembourg.

EU-OSHA (2023c), *Collaborative robot that automates sewing of bags in automotive supplier industry*, case study, Publications Office of the European Union, Luxembourg.

EU-OSHA (2023d), *Robotic system for palletising and depalletising products*, case study, Publications Office of the European Union, Luxembourg.

EU-OSHA (2023e), *Multi-axis robots for assembly automation and autonomous guided vehicles in manufacturing*, case study, Publications Office of the European Union, Luxembourg.

EU-OSHA (2023f), *Artificial intelligence-based vehicular automation fitted to excavators to automate trenching*, case study, Publications Office of the European Union, Luxembourg.

Eurofound (2013), *Employment polarisation and job quality in the crisis: European Jobs Monitor 2013*, Dublin.

Eurofound (2017), *Sixth European Working Conditions Survey – Overview report (2017 update)*, Publications Office of the European Union, Luxembourg.

Eurofound (2018a), *Automation, digitisation and platforms: Implications for work and employment*, Publications Office of the European Union, Luxembourg.

Eurofound (2018b), *Advanced industrial robotics: Taking human–robot collaboration to the next level*, Eurofound working paper, Dublin.

Eurofound (2019a), *Advanced robotics: Implications of game-changing technologies in the services sector in Europe*, Eurofound working paper, Dublin.

Eurofound (2019b), *Technology scenario: Employment implications of radical automation*, Publications Office of the European Union, Luxembourg.

Eurofound (2020a), *Employee monitoring and surveillance: The challenges of digitalisation*, Publications Office of the European Union, Luxembourg.

Eurofound (2020b), *Game-changing technologies: Transforming production and employment in Europe*, Publications Office of the European Union, Luxembourg.

Eurofound (2021a), *Tackling labour shortages in EU Member States*, Publications Office of the European Union, Luxembourg.

Eurofound (2021b), *Digitisation in the workplace*, Publications Office of the European Union, Luxembourg.

Eurofound (2021c), *Monitoring and surveillance of workers in the digital age*, research digest, Dublin.

Eurofound (2021d), *Impact of digitalisation on social dialogue and collective bargaining*, research digest, Dublin.

Eurofound (2022), *Ethics in the digital workplace*, Publications Office of the European Union, Luxembourg.

Eurofound (2023a), *Ethical digitalisation at work: From theory to practice*, Publications Office of the European Union, Luxembourg.

Eurofound (2023b), *Tackling rising inflation in sectoral collective wage bargaining*, Publications Office of the European Union, Luxembourg.

Euronews (2023), *Hospital in Bulgaria using robots to help doctors carry out surgery*, web page, accessed 3 April 2024.

European Commission (2020a), *European enterprise survey on the use of technologies based on artificial intelligence*, Publications Office of the European Union, Luxembourg.

European Commission (2020b), *European Skills Agenda for sustainable competitiveness, social fairness and resilience*, COM(2020)274 final, Brussels.

European Commission (2022a), *Proposal for a directive of the European Parliament and of the Council on adapting non-contractual civil liability rules to artificial intelligence (AI Liability Directive)*, COM(2022)496 final, Brussels.

European Commission (2022b), *Questions and answers on the revision of the Product Liability Directive*, web page, accessed 2 April 2024.

European Commission (2024), *Communication on boosting startups and innovation in trustworthy artificial intelligence*, COM(2024)28 final, Brussels.

European Commission (undated-a), *AI Act*, web page, accessed 29 March 2024.

European Commission (undated-b), *The European Pillar of Social Rights in 20 principles*, web page, accessed 15 April 2024.

European Parliament (2022), *A new EU strategic framework on health and safety at work post 2020 (including a better protection of workers from exposure to harmful substances, stress at work and repetitive motion injuries)*, 2021/2165(INI), Strasbourg.

Eurostat (2023), *European businesses statistics compilers' manual for ICT usage and e-commerce in enterprises: 2023 edition*, Publications Office of the European Union, Luxembourg.

Fernández-Macías, E., Klenert, D. and Anton, J. I. (2020), *Not so disruptive yet? Characteristics, distribution and determinants of robots in Europe*, JRC Working Papers Series on Labour, Education and Technology No. 2020-03, European Commission, Seville.

Findlay, P., Lindsay, C., McQuarrie, J., Bennie, M., Corcoran, E. D. and Van Der Meer, R. (2017), 'Employer choice and job quality: Workplace innovation, work redesign, and employee perceptions of job quality in a complex health-care setting', *Work and Occupations*, Vol. 44, No. 1, pp. 113–136.

Fletcher, S. R and Webb, P. (2017), 'Industrial robot ethics: The challenges of closer human collaboration in future manufacturing systems', in Ferreira, M. I. A., Sequeira, J. S., Tokhi, M. O., Kadar, E. E. and Virk, G. S. (eds.), *A world with robots: International Conference on Robot Ethics: ICRE 2015*, Springer, Cham, Switzerland, pp. 159–169.

Frey, C. B. and Osborne, M. A. (2013), *The future of employment: How susceptible are jobs to computerisation?* working paper, Oxford Martin Programme on Technology and Employment, Oxford.

Gihleb, R., Giuntella, O., Stella, L. and Wang, T. (2022), 'Industrial robots, workers' safety, and health', *Labour Economics*, Vol. 78, 102205.

Hacker, W. and Sachse, P. (2014), *Allgemeine Arbeitspsychologie: Psychische Regulation von Tätigkeiten*, 3rd ed., Hogrefe, Göttingen, Germany.

Heinold, E., Funk, M., Niehaus, S., Rosen, P. H. and Wischniewski, S. (2023), 'OSH related risks and opportunities for industrial human–robot interaction: Results from literature and practice', *Frontiers in Robotics and AI*, Vol. 10, 1277360.

ICE Cobotics (2023), 'Robotics continue to transform the commercial cleaning industry', blog post, 31 August.

IFR (International Federation of Robotics) (2022), *World robotics 2022: Industrial robots*, VDMA Services GmbH, Frankfurt.

IFR (2023), *World robotics 2023: Industrial robots 2023*, VDMA Services GmbH, Frankfurt.

ILO (International Labour Organization) and JRC (Joint Research Centre) (2024), *Algorithmic management practices in regular workplaces: Case studies in logistics and healthcare*, Publications Office of the European Union, Luxembourg.

Körner, U., Müller-Thur, K., Lunau, T., Dragano, N., Angerer, P. and Buchner, A. (2018), 'Perceived stress in human–machine interaction in modern manufacturing environments – Results of a qualitative interview study', *Stress and Health*, Vol. 35, No. 2, pp. 187–199.

Krupitzer, C., Lesch, V., Züfle, M., Kounev, S., Müller, S., Edinger, J. et al (2020), 'A survey on human machine interaction in Industry 4.0', *arXiv.org*.

Lasota, P. A., Fong, T. and Shah, J. A. (2014), 'A survey of methods for safe human–robot interaction', *Foundations and Trends in Robotics*, Vol. 5, No. 4, pp. 261–349.

Leso, V., Fontana, L. and Iavicoli, I. (2018), 'The occupational health and safety dimension of Industry 4.0', *La Medicina del Lavoro*, Vol. 109, No. 5, pp. 327–338.

Limerick Post (2022), 'Robotic surgery giving better outcomes at Limerick hospital', 10 March.

Liu, L., Guo, F., Zou, Z. and Duffy, V. G. (2022), 'Application, development and future opportunities of collaborative robots (cobots) in manufacturing: A literature review', *International Journal of Human–Computer Interaction*, Vol. 40, No. 8, pp. 1–18.

López, E. F., Gomez, M. O., Garcia, I. P., Gonzalez, M. S., Gil, J. A. D., Guell, E. M. et al (2016), 'DD-006 unit dose drug distribution system: How to improve the process in a tertiary hospital', *European Journal of Hospital Pharmacy*, Vol. 23, Suppl. 1, A107.

Lordan, G. and Neumark, D. (2018), 'People versus machines: The impact of minimum wages on automatable jobs', *Labour Economics*, Vol. 52, pp. 40–53.

Lui, J., Narsalay, R., Afzal, R., Nair Sharma, I. and Light, D. (2022), 'Research: How do warehouse workers feel about automation?' *Harvard Business Review*, 11 February.

Manokha, I. (2020), 'The implications of digital employee monitoring and people analytics for power relations in the workplace', *Surveillance and Society*, Vol. 18, No. 4, pp. 540–554.

ManpowerGroup (2024), *Talent shortages keep Belgian hiring intentions high for Q1 2024*, web page, accessed 3 April 2024.

Meyer, S. C., Tisch, A. and Hünefeld, L. (2019), 'Arbeitsintensivierung und Handlungsspielraum in digitalisierten Arbeitswelten – Herausforderung für das Wohlbefinden von Beschäftigten?' *Industrielle Beziehungen – Zeitschrift für Arbeit, Organisation und Management*, No. 2/2019, pp. 207–231.

Milanez, A. (2023), *The impact of AI on the workplace: Evidence from OECD case studies of AI implementation*, OECD Social, Employment and Migration Working Papers No. 289, OECD Publishing, Paris.

MMR (Maximize Market Research) (2023), *Social robots market: Global industry analysis and forecast (2023–2029)*, web page, accessed 3 April 2024.

Onnasch, L. and Roesler, E. (2021), 'A taxonomy to structure and analyze human–robot interaction', *International Journal of Social Robotics*, Vol. 13, No. 4, pp. 833–849.

Onnasch, L., Wickens, C. D., Li, H. and Manzey, D. (2014), 'Human performance consequences of stages and levels of automation: An integrated meta-analysis', *Human Factors*, Vol. 56, No. 3, pp. 476–488.

Palmarini, R., Fernandez del Amo, I., Bertolino, G., Dini, G., Ahmet Erkoyuncu, J., Roy, R. et al (2018), 'Designing an AR interface to improve trust in human–robots collaboration', *Procedia CIRP*, Vol. 70, pp. 350–355.

Pancardo, P., Acosta, F. D., Hernández-Nolasco, J. A., Wister, M. A. and López-de-Ipiña, D. (2015), 'Real-time personalized monitoring to estimate occupational heat stress in ambient assisted working', *Sensors*, Vol. 15, No. 7, pp. 16956–16980.

Pauliková, A., Gyurák Babeľová, Z. and Ubárová, M. (2021), 'Analysis of the impact of human–cobot collaborative manufacturing implementation on the occupational health and safety and the quality requirements', *International Journal of Environmental Research and Public Health*, Vol. 18, No. 4, 1927.

Petzoldt, C., Harms, M. and Freitag, M. (2023), 'Review of task allocation for human–robot collaboration in assembly', *International Journal of Computer Integrated Manufacturing*, Vol. 36, No. 11, pp. 1675–1715.

Pfeiffer, S. (2016), 'Robots, Industry 4.0 and humans, or why assembly work is more than routine work', *Societies*, Vol. 6, No. 2, 16.

Smids, J., Nyholm, S. and Berkers, H. (2020), 'Robots in the workplace: A threat to, or opportunity for, meaningful work?' *Philosophy and Technology*, Vol. 33, No. 3, pp. 503–522.

Smith, E. R., Sherrin, S., Fraune M. R. and Sabanovic, S. (2020), 'Positive emotions, more than anxiety or other negative emotions, predict willingness to interact with robots', *Personality and Social Psychology Bulletin*, Vol. 46, No. 8, pp. 1270–1283.

Tantawi, K. H., Sokolov, A. and Tantawi, O. (2019), *Advances in industrial robotics: From Industry 3.0 automation to Industry 4.0 collaboration*, Institute of Electrical and Electronics Engineers, New York.

Tausch, A., Kluge, A. and Adolph, L. (2020), 'Psychological effects of the allocation process in human–robot interaction – A model for research on ad hoc task allocation', *Frontiers in Psychology*, Vol. 11, 564672.

Verified Market Research (2023), *Collaborative robot (cobot) market size and forecast*, web page, available at https://www.verifiedmarketresearch.com/product/collaborative-robot-cobot-market/, accessed 7 May 2024.

Wasen, K. (2005), 'Person-friendly robot interaction: Social, psychological and technological impacts in health care work', *ROMAN 2005: IEEE International Workshop on Robot and Human Interactive Communication*, Institute of Electrical and Electronics Engineers, New York, pp. 643–648.

Weidemann, C., Mandischer, N., van Kerkom, F., Corves, B., Hüsing, M., Kraus, T. et al (2023), 'Literature review on recent trends and perspectives of collaborative robotics in Work 4.0', *Robotics*, Vol. 12, No. 3, 84.

Wurhofer, D., Meneweger, T., Fuchsberger, V. and Tscheligi, M. (2015), 'Deploying robots in a production environment: A study on temporal transitions of workers' experiences', conference presentation, 15th IFIP TC13 Conference on Human–Computer Interaction: INTERACT 2015, 14–18 September, Bamberg, Germany.

Zorzenon, R., Lizarelli, F. L. and Daniel, B. D. A. (2022), 'What is the potential impact of Industry 4.0 on health and safety at work?' *Safety Science*, Vol. 153, No. 11, 105802.

Annex

Table A1: Results of fixed-effects logistic regressions of the association between using robots at work and working conditions

	Model 1	Model 2	Model 3	Model 4	Model 5
	Increase workload	Determine speed of work	Reduce autonomy	Increase surveillance of work	Result in working alone
Gender (ref. male) Female	1.089* (0.040)	1.054 (0.035)	0.940* (0.028)	0.970 (0.034)	1.126** (0.048)
Age	1.006** (0.002)	0.992*** (0.002)	1.000 (0.002)	0.996** (0.002)	1.000 (0.001)
Education (ref. primary) Secondary	1.163 (0.169)	1.300** (0.112)	1.240 (0.243)	1.059 (0.109)	1.477** (0.185)
Tertiary	1.206 (0.170)	1.761*** (0.172)	1.119 (0.229)	1.001 (0.112)	1.591*** (0.199)
Temporary contract	1.002 (0.051)	0.962 (0.043)	1.006 (0.065)	1.031 (0.045)	0.918* (0.039)
Contract duration (ref. part time) Full time	1.157* (0.082)	1.325*** (0.085)	1.018 (0.059)	1.090 (0.050)	0.999 (0.049)
Occupation (ref. skilled occupations) Elementary occupations	0.812** (0.055)	0.560*** (0.063)	0.841 (0.098)	0.741* (0.087)	0.653*** (0.071)
Managers and professionals	1.172*** (0.046)	1.175*** (0.043)	0.939 (0.060)	0.867*** (0.036)	1.005 (0.045)
Sector (ref. manufacturing) Agriculture	1.013 (0.108)	0.978 (0.107)	1.280 (0.167)	0.994 (0.118)	1.251* (0.133)
Construction	0.943 (0.075)	0.812** (0.064)	0.950 (0.064)	0.854** (0.051)	0.832* (0.070)
Services	1.196*** (0.060)	1.023 (0.052)	1.023 (0.051)	1.053 (0.053)	1.022 (0.048)
Use robots at work	1.284** (0.105)	1.644*** (0.128)	1.338** (0.132)	1.420*** (0.102)	1.247* (0.108)
Logged variance of random effect	0.105*** (0.023)	0.130*** (0.034)	0.309*** (0.087)	0.124*** (0.037)	0.126*** (0.051)
Observations	**19,299**	**19,361**	**19,231**	**19,131**	**19,257**

Note: *Exponentiated coefficients, with standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.*
Source: *Authors' own calculations, based on OSH Pulse survey data*

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://european-union.europa.eu/contact-eu_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

– by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls)

– at the following standard number: +32 22999696

– by email via: https://european-union.europa.eu/contact-eu_en

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu

EU publications

You can download or order free and priced EU publications at: https://op.europa.eu/publications
Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://european-union.europa.eu/contact-eu_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1952 in all the official language versions, go to EUR-Lex at: https://eur-lex.europa.eu

Open data from the EU

The EU Open Data Portal (https://data.europa.eu) provides access to datasets from the EU. Data can be downloaded and reused for free, both for commercial and non-commercial purposes.

EF/23/010

TJ-09-24-447-EN-N

The extent of interaction between workers and robots is expected to increase in modern workplaces due to rapid advancements in robotic technologies. Advanced robotics often leverages progress in artificial intelligence, machine learning and sensor technologies to achieve higher levels of sophistication and versatility. The enhanced capabilities of new-generation robots facilitate increased collaboration between humans and robots, partly by ensuring safety when humans and robots are working in proximity. This marks a move away from traditional robots, often confined to cages on the shop floor to isolate them from human operators. In spite of the many benefits, there are lingering concerns around the requirement for workers to continually adapt to new or changing tasks and roles, the possibility of monitoring workers' activities at an unprecedented level of granularity, diminished autonomy and control over the pace of work, and the emergence of new health and safety risks, including of a psychosocial nature. Drawing on survey data and case studies investigating advanced robotic systems and applications, this report explores the opportunities and challenges that come with closer human–robot interaction, with a view to contributing to the broader policy debate on the automation of work.

The European Foundation for the Improvement of Living and Working Conditions (Eurofound) is a tripartite European Union Agency established in 1975. Its role is to provide knowledge in the area of social, employment and work-related policies according to Regulation (EU) 2019/127.

Publications Office of the European Union

ISBN 978-92-897-2409-8
doi:10.2806/601796