AGILEHAND

D2.3 – AGILEHAND Handbook including Strategies for Employees' Skills Development, Health and Safety, Communication and Engagement V1

WP2 – NEED: Industrial Scenarios and SSH Requirements Analysis

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ABSTRACT	This handbook presents the first version of a comprehensive guide developed as part of the AGILEHAND project, aimed at facilitating the adoption of Industry 4.0 technologies in the food sector. The handbook covers various aspects of digital transformation, including the impact of digitalisation, automation and artificial intelligence on production processes and workforce dynamics. It addresses regulatory frameworks, ethical considerations and the crucial role of human factors in technological transformation. The handbook also explores the ideal methods for implementing occupational safety and health systems in digital contexts and provides best practices for a successful transition to Industry 4.0. This version offers a theoretical foundation based on bibliographical research and case studies, while the final version will incorporate empirical data from the project's implementation phase. The handbook serves as a valuable resource for		

	companies, workers and stakeholders looking to integrate Industry 4.0 technologies into their operations and strategies.

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ABBREVIATIONS/ACRONYMS

AET	Affective Events Theory
AI	Artificial Intelligence
AR	Augmented Reality
BDBA	Big Data Business Analytics
CPS	Cyber-Physical Systems
EU	European Union
GDPR	General Data Protection Regulation
HR	Human Resources
HRC	Human-Robot Collaboration
ICT	Information and Communication Technologies
InSyeme	Integrated System and Extended Management Evolution
IoT	Internet of Things
IT	Information technology
MEPS	Manufacturing Execution Planning System
NER	New Emergent Risks
OSH	Occupational Safety and Health
ROP	Responsible Order of Production
SMEs	Small and Medium-Sized Enterprises
SPI	Safety Performance Indicators
TAM	Technology Adoption Model
UTAUT	Unified Theory of Acceptance and Use of Technology

Executive summary

This comprehensive handbook, developed as part of the EU-funded AGILEHAND project, aims to help the food sector adopt Industry 4.0 technologies. The handbook presents the preliminary results of the research and analysis carried out to date, focusing on the integration of intelligent solutions for the classification, handling and packaging of soft and deformable food products. The handbook is structured in seven sections, covering the main aspects of digital transformation in the food industry:

1. Digital transformation in the food industry
2. Regulatory landscape and ethical considerations
3. Human factors
4. Implementing OSH in a digital context
5. Case studies on production and technology
6. Best practices and lessons learnt
7. Future perspectives

The document explores the impact of digitalisation, automation and artificial intelligence on production processes, work organisation and the workforce. It addresses regulatory frameworks, ethical considerations and the crucial role of human capital in responding to technological transformation. The guide also analyses the ideal methods for establishing occupational safety and health (OSH) systems in digital environments and summarises best practices for a successful transition to Industry 4.0. This version (v1) of the guide provides a solid theoretical basis for the AGILEHAND project. The final version (v2) will incorporate empirical data and conclusions drawn during the implementation phase, which is scheduled to begin in 2025.

Document structure

Section 1: Digital Transformation in the Food Industry

Section 2: Regulatory Landscape and Ethical Considerations

Section 3: Human Factors

Section 4: Implementing OSH in a Digital Context

Section 5: Case Studies on Production and Technology

Section 6: Best Practices and Lessons Learned

Section 7: Future Outlook

Introduction

The forthcoming era of industry 4.0 is promoting the spread of cloud and Internet of Things (IoT) technologies as the key-enablers of a new interconnected working environment where machines and human operators are supposed to cooperate within a smart production system. Coherently with such view, the manufacturers of operating machines are implementing artificial intelligence in their products, transforming automated machines into cyber physical systems (CPS), with advanced interoperability features and ideally capable of coordinating with each other autonomously. CPS are thus supposed to be the manufacturing resources of next generation capable of interacting with each other, with the environment and with the human operators in seamless integrated production environment. This idyllic view of the future smart production systems arises some fundamental questions about the role of the human operator in the working environment of the future, and how will this interaction with smart CPS take place. The risk of underestimating such issues, leaving the man in the background of an industrial revolution focused on technology, exists and it would eventually lead towards a general deterioration of the worker's physical and psychological condition. Unfortunately, we have recent experiences which ring an alarm bell in such sense. Rethinking appropriately the role of the human operator in the production system is probably the main challenge that must be taken up by ergonomics in the 4th industrial revolution

This document presents the first version of a comprehensive guidebook created to help the food sector adopt Industry 4.0 technologies. The European Union-funded AGILEHAND project seeks to provide clever solutions for the classification, handling, and packaging of soft and deformable food products. The purpose of version 1 of the manual is to publicise the preliminary results of the research and analysis carried out to date. The final version (v2) will be made available after the start of the project's implementation phase, scheduled for 2025, and will incorporate the data and conclusions obtained during this crucial stage.

The decision to create two versions of the handbook arises from the need to provide a robust theoretical foundation prior to the actual implementation of AGILEHAND technology. The literature research, including diverse case studies and pertinent publications, enhanced our comprehension of the difficulties and possibilities intrinsic to the digitisation of the food business.

The application of the selected research methods in the project's four pilots - covering the vegetable, fruit, meat and fish sectors - will provide valuable empirical data for drawing up the final version of the manual.

The manual is organised into seven distinct sections, each addressing a key aspect of digital transformation in the food industry. Sections 1 to 4 and 6 and 7 explore topics such as:

Digital transformation: This section provides an overview of the main Industry 4.0 technologies and their impact on production processes, work organisation and the workforce.

Regulatory framework and ethical considerations: Addresses the European and national policies and regulations (Spain, Portugal, Italy and Belgium) that shape the implementation of digital technologies in the food sector, with an emphasis on occupational health and safety standards.

Human factors: Analyses the essential significance of human capital in responding to technology transformation, emphasising organisational change management, skills enhancement, group dynamics, risk assessment, and psychological hazards.

Implementing OSH in a digital context: Analyses optimal methods for the establishment of occupational safety and health (OSH) systems inside digital settings, including the phases of design, implementation, transition, and operation of novel technologies.

Best practices and lessons learnt: Summarises the principal suggestions for a successful transition to Industry 4.0, derived from a literature analysis and expert interviews.

Future outlooks: Examines forthcoming trends and problems of digitisation in the food sector, predicting its effects on work organisation, employee competencies, and occupational health and safety.

Section 5, dedicated to case studies, will be further developed in version 2 of the manual, with the inclusion of detailed data on the four AGILEHAND project pilots.

In addition, version 2 will have a chapter dedicated to stakeholders, presenting the results of the interviews carried out, and two sub-chapters, one on Japan and the other on Sister Projects.

While the 'Sister Projects' sub-chapter will explore the parallels, difficulties, and solutions used in comparable projects, the Japan sub-chapter will look at safety regulations, cultural differences, and human resource management practices in the country.

The AGILEHAND program has made great strides in raising awareness of digital transformation in the food industry with the introduction of version 1. A valuable resource for businesses, workers, and other stakeholders looking to integrate Industry 4.0 into their operations and strategies, the final version of the handbook will be improved by the results of the technology deployment in the pilot projects. To gather empirical data about the impact of digitalisation on work processes, employee health and safety, and organisational culture, AGILEHAND technologies will be used in trial projects starting in 2025.

The development of a thorough and up-to-date handbook to support the food industry's transition to sector 4.0 will need this empirical data.

Digital Transformation in the Food Industry

1.1 Overview of Digitalisation, Automation, and Artificial Intelligence (AI) Technologies

The food industry is undergoing a significant revolution as digital technology, automation, and AI advance. Essential facilitators of Industry 4.0, these technologies are altering industrial processes to raise productivity, quality, and sustainability (Amentae & Gebresenbet, 2021; Demartini et al., 2018). Their influence spans world food industries, transforming agricultural methods, streamlining supply networks, and enhancing consumer interactions (Camaréna, 2020; Miranda et al., 2019; Nagy et al., 2020; Raheem, 2020). Digitalisation in the food industry encompasses sophisticated tools such as blockchain, the Internet of Things (IoT), and big data analytics. These technologies improve food safety and quality assurance by increasing traceability and openness throughout the supply chain (Amentae & Gebresenbet, 2021).

Automation enhances digitalisation by using robots and AI to expedite operations, minimise manual labour, and boost production (Romanello & Veglio, 2022). Automated technologies help to regulate manufacturing processes from farm to table properly, improving product quality and lowering waste (Miranda et al., 2019; Raheem, 2020). Additionally, robotic technologies boost food production productivity and cost efficiencies while offering sustainable solutions for the industry (Camaréna, 2020; Nagy et al., 2020).

The ability of AI to evaluate and analyse enormous volumes of data improves operational efficiency and decision-making, aiding process optimisation (Nagy et al., 2020; Raheem, 2020). Via vertical integration and current production techniques, automation and digital technologies in food processing provide higher sustainability and efficiency (Romanello & Veglio, 2022). These developments let the food industry meet both environmental goals and consumer needs for rising consumption.

1.2 Human-Robot Collaboration

Cooperation between people and robots has become necessary for digital transformation across many sectors, particularly in Industry 4.0. This cooperation aims to enable the smooth integration of employees with developing technology, create policies to improve human-machine interaction and promote a corporate culture of cooperation.

In the food industry, including people with new technology is becoming more critical. Automation helps perform jobs accurately and consistently, transforming employees' roles and responsibilities. Conventional responsibilities in the food industry have changed as robots and automated technologies may now do activities traditionally handled by human operators alone. Those activities can include applying subtle changes and working in situations unsuitable for human presence, including sterile surroundings or extended low-temperature exposure (Caldwell, 2012). One clear example of human-machine cooperation in the food industry, is the meat processing sector. Companies should efficiently use augmented reality, speech and gesture recognition, and laser projection to cut trajectories (Romanov et al., 2022) and improve the integration of personnel with new technology. Implementing new technologies can improve communication and human-robot collaboration in the workplace.

Formulating policies that enhance the human-robot collaboration is essential for achieving effective digital transformation. Effectively managing cultural change in companies that adopt Industry 4.0 technologies plays a significant role. The effective adoption of these technologies has the potential to foster beneficial cultural transformations within companies, setting the stage for ongoing advancements and innovations. This indicates that policies should prioritise the technical dimensions of human-machine collaboration and cultivate a culture that welcomes technological progress (Konur et al., 2023).

In the field of human-robot collaboration, encouraging a cooperative working culture is very vital. Turning to more flexible manufacturing techniques and integrating cyber-physical systems requires more general knowledge. This change calls for staff members who can cooperate in teams and handle technical difficulties related to sophisticated manufacturing systems. Human Resources (HR) must create strategies to address resistance to change, especially as the shift to Industry 4.0 presents considerable challenges for vocational education and the skills required to maintain and operate highly automated and flexible manufacturing systems (Madsen et al., 2016).

Combining process control with robots and automation has resulted in apparent changes in people's roles and obligations in the food industry. This is because automation helps ensure correct and consistent work performance, significantly modifying traditional responsibilities in the food industry. The rise of new roles and specialisations is apparent, as robots and automated systems can now undertake tasks that were once done by humans (Caldwell, 2012; Romanov et al., 2022).

Companies must create thorough strategies that consider the technological and human dimensions to enhance the human-robot collaboration. Controlling cultural change and promoting new competencies is essential, so policies should prioritise training and skill development (Konur et al., 2023; Madsen et al., 2016). These strategies will help employees successfully interact with new technology.

Integrating new technologies relies on human-robot collaboration. Careful attention to technical integration, policy creation, and encouragement of a supportive culture is significant. Integrating employees and promoting a culture of cooperation in the workplace help companies address the challenges and leverage the advantages of human-robot collaboration.

1.3 Technology Acceptance by Employees

The Technology Acceptance Model (TAM) seeks to predict and explain the adoption of new technology. First published by Davis (1989), it holds that two fundamental ideas (perceived utility and ease of use) define a person's drive to use technology (Venkatesh et al., 2003). Perceived utility is "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989, p. 320).

TAM has been widely used to examine how different technologies are adopted in various settings. To apply TAM, it’s necessary to distribute questionnaires to potential technology users, eliciting their thoughts on its usefulness, usability and their likelihood to use it. Multi-item scales are often used to test these dimensions, and answers are gathered at various intervals to record shifts in users' intents and perceptions as they get more used to the technology (Venkatesh et al., 2003).

One of TAM's primary benefits is its ability to account for a considerable portion of the variance in user intentions and behaviour. Research has repeatedly shown that TAM may explain at least 40% of the variation in these results (Venkatesh et al., 2003). Because of its predictive potential, TAM is a useful tool for managers and system designers who need to determine the chances of success for new technology deployments.

Companies may tailor their activities to focus on the most relevant components by assessing the relative effect of perceived utility and perceived ease of use in increasing acceptance. If it is discovered that the adoption of new technology is mostly driven by perceived utility, managers may focus on explaining the technology's benefits and value proposition to prospective customers.

Despite its benefits, TAM has down backs and limitations. One criticism is that the model simplifies the complex process of technology adoption by focusing simply on two belief structures. Additionally, concerns have been raised about using TAM in situations when utilisation is required. Since most early TAM research centred on voluntary adoption circumstances, some scholars argue that the paradigm may not be as suitable in settings where technology use is mandated.

Another concern is when self-reported surveys are used to assess all dimensions, the possibility of common technique bias arises. To counteract this, researchers are urged to adopt longitudinal designs that segregate the measurement of independent and dependent variables and objective measurements of system utilisation (Venkatesh et al., 2003).

To address this problem, scientists have proposed the Unified Theory of Acceptance and Use of Technology (UTAUT), which include additional factors such as performance expectancy, effort expectancy, social influence and facilitating conditions.

Companies should consider essential factors when analysing the elements that affect the acceptability of automation. These factors include faith in technology, working circumstances, job happiness, user age, work experience, and past automation exposure (Bekier & Molesworth, 2017).

German food industry businesses are considering how digital technologies affect staff roles, responsibilities, and training demands (Achtenhagen & Achtenhagen, 2019). Promising methods for digital transformation need thorough evaluation, emphasising the necessity of regularly monitoring training requirements in terms of the feasibility of adopting new technologies (Achtenhagen & Achtenhagen, 2019). These programs guarantee that employees are prepared to succeed in the face of new technology by encouraging an always-learning, flexible culture. Businesses can guarantee a smooth transition for every employee into the digital age by investing in workforce development, which boosts employee competency and confidence.

1.4 Transformative Effects on Labour Markets and Workforce

Adopting Industry 4.0 ideas, such as smart factories, emphasises the need for employees knowledgeable about modern technology. Automation improves accuracy and efficiency, especially in repetitive operations, while digitalisation makes it possible to gather and analyse vast amounts of data for well-informed decision-making. AI improves these processes using operation simplification, demand prediction, and product innovation promotion (Hernandez-de-Menendez et al., 2020). Other technologies such as virtual reality, 3D printing, and the IoT (Hernandez-de-Menendez et al., 2020), are also helping industrial settings to adapt and cooperate.

Despite recent developments, challenges remain in transitioning to a technologically oriented economy, including talent shortages and job losses. New technologies increase the demand for jobs requiring creativity, social connection, and sophisticated problem-solving abilities (Muro et al., 2019), automation lowers the need for repeated manual activities. This change emphasises the need to change the workforce by training courses that provide staff members with the necessary abilities in data analytics, AI programming, and machine learning (Varshney, 2020). Fostering a culture of lifelong learning enables businesses to help their employees thrive in a changing environment.

The food industry must combine technical innovations with workforce-oriented operations to reduce the likelihood of social problems. Although highly competent people have chances thanks to automation and digitalisation, they also need training programs, and educational institutions change. Extensive training programs and curriculum integration of AI-related skills are two proactive projects that can help to build a more equitable and sustainable future (Camaréna, 2020; Miranda et al., 2019; Nagy et al., 2020; Raheem, 2020).

The intersection of digitalisation, automation, and AI will improve customer connections, sustainability, and efficiency and hence cause significant transformation in the food industry. However, reaching these benefits will involve addressing labour problems and ensuring that human-centred adaptation methods complement technological developments. This balanced approach is crucial for the food industry's strong and inclusive future.

1.5 Digitalisation in Occupational Safety and Health (OSH)

Integrating new technologies into the workplace also poses challenges, particularly concerning OSH. The erratic pace at which these technologies are adopted, often due to insufficient organisational preparedness, raises concerns about the potential shift from proactive to reactive OSH measures (Polak-Sopinska et al., 2020).

Digital technologies enable manufacturers to model, communicate, and execute operations more effectively. With these technologies, firms can improve production and product assembly processes, automate production management procedures, and continuously enhance work procedures while minimising errors (Mijatović et al., 2020). In the food industry, where precision and hygiene are paramount, such advancements can lead to safer and more efficient operations. Nevertheless, the success of these implementations depends on the readiness of companies to embrace these changes. Unfortunately, only a significant portion of manufacturers know how to integrate their solutions with external infrastructures effectively, and even fewer have solid business foundations to support the implementation of new technologies. This lack of preparedness can deteriorate work quality and increase workplace injuries and accidents (Polak-Sopinska et al., 2020).

Collaborative robots, or cobots, which operate alongside human employees, are increasingly popular in the food industry. These robots offer new ways of performing routine operations and are designed to work alongside humans safely, recognise their surroundings and eliminate non-typical situations, thus improving employees' safety (Badri et al., 2018; Moore, 2019; Polak-Sopinska et al., 2020). While preventing some risks, they can also create new ones (Arana-Landín et al., 2023; Badri et al., 2018; Moore, 2019).

Before a business adopts automation, it must understand how it will affect OSH management systems. It is not the technology that generates positive or negative OSH conditions but how it is implemented and managed (European Agency for Safety and Health at Work, 2018). Haste, lack of clear communication and employees' involvement, human-centred design, and early OSH management effectively address most aspects (European Agency for Safety and Health at Work & Future Impacts., 2023; Moore, 2019), taking the most from automation to make safer workplaces. Good ergonomics, active or passive safety features, and employees' competencies contribute to OSH objectives (Gutsche & Droll, 2020).

1.6 Impacts of Industry 4.0 on the Food Industry

The combination of automation, digitalisation, and AI revolutionises the food industry. While encouraging efficiency, precision, and sustainability, these changes affect labour markets and employment dynamics. Successful integration of these technologies depends on a solid awareness of their implications and proactive methods of employee adaption.

1.6.1 Benefits of Implementing Digitalisation, Automation and AI in the Food Industry

Integrating digitalisation, automation, and AI into the food industry enhances efficiency, supply chain management and manufacturing. AI, digital technology, and Industry 4.0 innovations might help the food industry to optimise processes, cut waste, use less energy, and better manage resources (Camaréna, 2020; Miranda et al., 2019; Nagy et al., 2020; Raheem, 2020). This improvement reduces operating costs while improving performance and productivity.

Increased traceability is another significant advantage. Digital technology helps ensure the safety and quality of food products by monitoring them along the supply chain (Amentae & Gebresenbet, 2021). Intelligent logistics, blockchain technology, IoT, and AI-powered data analysis improve supply chain visibility by enabling improved tracking of agricultural goods from the field to the customer's plate (Bajic et al., 2021; Camaréna, 2020; Miranda et al., 2019; Nagy et al., 2020; Raheem, 2020). It lowers the possibility of food fraud, ensures authenticity, and minimises waste.

Additionally, the combination of several Industry 4.0 technologies enhances data-driven decision-making. These technologies facilitate data collection, analysis, and use at every food production and distribution stage. It facilitates forecast analytics, adaptive management techniques, and well-informed decision-making, all of which increase overall operational efficiency (Bajic et al., 2021; Miranda et al., 2019; Nagy et al., 2020).

IoT and other Industry 4.0 technologies increase data collecting to allow for more accurate customisation, which might lead to better health outcomes and a minor environmental impact (Bajic et al., 2021; Camaréna, 2020; Raheem, 2020). A significant benefit of this improved user experience is that it satisfies the rising demand from customers for specialised goods and services.

The technologies from industry 4.0 increase sustainability. By integrating AI, digital tools, and other Industry 4.0 technologies, the food industry may concentrate on renewable energy, cut resource consumption, and lessen its carbon footprint. By monitoring and optimising energy use, these technologies support sustainable consumption and agricultural practices.

Utilising these technologies promotes industrial innovation and adaptation. They create new goods, services, and business models. In addition to successfully meeting changing customer expectations, this encourages creativity, adaptability, and agility in facing problems (Bajic et al., 2021; Camaréna, 2020; Miranda et al., 2019; Nagy et al., 2020).

Another area where Industry 4.0 technology might be beneficial is predictive maintenance. In food processing and packaging, IoT sensors and AI algorithms increase equipment performance and decrease machine downtime (Bajic et al., 2021; Nagy et al., 2020). Subsequently, food safety and consumer satisfaction are raised (Bajic et al., 2021; Miranda et al., 2019; Raheem, 2020).

Industry 4.0 technologies benefit from OSH, through enhancing workplace safety, working conditions, and overall industry productivity. One key advantage is their ability to remove employees from hazardous situations. Robotics and automation, for instance, enable machines to undertake dangerous, monotonous, and unpleasant tasks that often cause workplace injuries. They can function in dangerous environments, thereby reducing the physical and psychological risks faced by employees (Arana-Landín et al., 2023; European Agency for Safety and Health at Work, 2019; Horton et al., 2018).

Implementing these technologies can improve work environments, shorter processing times, better operations management, more efficient decision-making, and increased productivity. They also facilitate real-time sensing, rapid information transmission, and enhanced stakeholder collaboration (Arana-Landín et al., 2023).

OSH can benefit from innovative approaches such as more effective monitoring of employees' exposure, automation of repetitive and monotonous tasks, conducting advanced workplace risk assessments, improved communication and OSH inspections, and enhanced prevention mechanisms that lead to fewer accidents and injuries (European Agency for Safety and Health at Work, 2019; Heinold et al., 2023; Horton et al., 2018).

These technologies can significantly reduce employees' exposure to hazardous, such as chemical, biological, and physical risks (Arana-Landín et al., 2023; European Agency for Safety and Health at Work, 2018). In food industry, automation can minimise the need for employees to work in low-temperature environments and reduce manual load handling. Some industries have already implemented technology that reduces occupational illnesses and work-related accidents, such as musculoskeletal disorders, by eliminating repetitive actions and preventing ergonomic discomfort (Tepe, 2021).

Automation of physical tasks can also positively impact employees' cognitive load and well-being. By reliably performing tasks, these systems relieve employees from planning and executing certain operations, reducing the mental energy required for safety monitoring (Heinold et al., 2023; Kadir & Broberg, 2020).

Technological advancements have also improved environmental risk monitoring and accident prevention capabilities. Employees' safety and health conditions can be monitored in real-time, dangerous situations can be detected, and employees can be alerted to risks, allowing for proactive intervention (Horton et al., 2018; Lemos et al., 2022). The future of OSH is likely to be shaped by machines with self-awareness, self-learning, and self-healing capabilities that can predict potential workplace hazards and manage unexpected conditions. These advanced systems, equipped with sensors, cameras, and sophisticated programming, will further enhance accident prevention and employee safety (Polak-Sopinska et al., 2020).

Advanced technologies provide employees with greater autonomy and flexibility and facilitate the inclusion of vulnerable groups such as older employees, disabled individuals, and caregivers (European Agency for Safety and Health at Work, 2019). Furthermore, digitalisation offers opportunities for more effective OSH training (European Agency for Safety and Health at Work, 2019). Virtual reality can be used for training, reducing exposure to hazards during learning (European Agency for Safety and Health at Work, 2018). Some researchers predict a decline in physical and psychological workplace injuries by 2030 due to the widespread adoption of automation (Horton et al., 2018).

Modern technology has numerous benefits, but it is essential to properly apply changes to working circumstances and assess how they influence OSH hazards, considering both present and future dangers (Arana-Landín et al., 2023).

The food industry can benefit from Industry 4.0 technologies, including increased productivity, sustainability, traceability, consumer satisfaction, innovation potential, data-driven decision-making, predictive maintenance processes, and improved quality control techniques. When these technologies are coupled, they strengthen and maintain the food industry, improve its ability to meet future demands and provide safer and more productive working conditions.

1.6.2 Challenges of Implementing Digitalisation, Automation and AI in the Food Industry

Industry 4.0 technologies in the food industry have several barriers that impede their widespread implementation. The primary concern is the high initial expense of integrating these modern technologies. The expenses associated with hardware, software, and infrastructure may be too costly for small and medium-sized enterprises (Bajic et al., 2021; Demartini et al., 2018; Miranda et al., 2019; Nagy et al., 2020; Raheem, 2020). The need for specialised technical skills and experience deepens this expensive obstacle, demanding substantial training to address existing skill deficiencies (Romanello & Veglio, 2022).

Concerns surround the possibility that digitalisation and automation may benefit bigger producers and developed economies, exacerbating existing inequalities (Camaréna, 2020). Equitable access and benefit-sharing are essential to avert the widening gap (Bajic et al., 2021; Camaréna, 2020).

Integrating Industry 4.0 technologies prompts data privacy and cybersecurity concerns. Enhanced data connection renders sensitive information susceptible to breaches and cyber-attacks, necessitating robust security measures (Bajic et al., 2021; Camaréna, 2020; Hassoun et al., 2023; Miranda et al., 2019; Nagy et al., 2020; Raheem, 2020). The intricacies of AI systems and digital solutions generate apprehensions about transparency and dependability. A lack of comprehension of decision-making processes may undermine stakeholder trust and restrict regulatory compliance across several sectors.

Another challenge industries face when integrating Industry 4.0 technologies is a reluctance to change. Employees often hold back from embracing new technology because they are concerned about job security and fear that their familiar workflows might be disrupted (Lloyd & Payne, 2023). Outdated food industry practices and corporate aversion to innovation often cause reluctance, postponing the integration of Industry 4.0 technologies.

It is impossible to ignore the significant impact of AI on the environment. Despite the benefits of AI and other Industry 4.0 technologies, they intensify environmental challenges due to increased energy consumption and carbon emissions associated with data processing activities (Bajic et al., 2021; Camaréna, 2020). Substantial issues emerge from inadequacies in infrastructure. Successful implementation requires a robust digital infrastructure with reliable internet access and technical support. Inadequate infrastructure presents difficulties (Bajic et al., 2021; Miranda et al., 2019; Raheem, 2020).

Integrating new technologies into existing systems presents several challenges, requires significant reorganisation and adaptation of existing operational frameworks (Bajic et al., 2021; Nagy et al., 2020; Raheem, 2020). Ongoing innovation and adaptation are necessary to meet industry-specific requirements (Bajic et al., 2021; Nagy et al., 2020).

The rapid advancement of Industry 4.0 technologies presents significant challenges for OSH that must be carefully managed to ensure employee safety and well-being. While these technologies offer numerous benefits, they also introduce complex risks and obstacles across technological, human, organisational, and ethical dimensions.

Task design is another critical consideration during the implementation of advanced technologies. Automation can reduce employees' involvement in specific aspects of a task or, conversely, lead to task integration that may increase their workload. Companies must carefully determine which tasks will remain human-centric to avoid over-reliance on technology. Ensuring that employees are assigned meaningful responsibilities, rather than merely those tasks that robotic systems cannot yet automate, is essential for sustaining employee engagement and preserving vital human skills (European Agency for Safety and Health at Work & Future Impacts., 2023).

From a technological perspective, integrating AI and robotics into the workplace introduces specific risks. Human-robot interactions, particularly in environments using cobots, can create new hazards, such as robot-human collisions due to unpredictable robot behaviour driven by machine learning algorithms (European Agency for Safety and Health at Work, 2019). Additionally, reliance on internet-connected systems exposes these technologies to cybersecurity vulnerabilities, potentially compromising safety-critical functions. Environmental risks such as sensor degradation or unexpected human actions in unstructured environments can also emerge, leading to unforeseen dangers (Moore, 2019).

The rapid evolution of these technologies often outpaces the availability of suitable systems, compelling companies to develop custom solutions or make significant adjustments to existing systems. Aligning new technologies with current tasks, safety standards, and legislative requirements can lead to cost overruns and the need for additional safety measures, potentially reducing overall system performance. These challenges may sometimes discourage companies from implementing certain technologies altogether (European Agency for Safety and Health at Work & Future Impacts., 2023).

Digitalisation and automation also present new safety and ergonomic challenges, cybersecurity, and functional safety risks. The interconnected nature of modern workplaces heightens the potential for cyberattacks that could jeopardise employee safety. Additionally, the constant pressure on employees to keep pace with automated systems can increase performance demands, negatively affecting mental health. In highly automated environments, reduced human interaction exacerbates these psychosocial risks, further underscoring the importance of addressing the broader implications of these technological advancements (European Agency for Safety and Health at Work, 2019; Horton et al., 2018).

The transition from work environments to those dominated by advanced technologies brings its own set of challenges. One significant issue is the ergonomic impact of sedentary work and increased interactions with robots. As automation takes over more physical tasks, employees may find themselves in more sedentary roles, leading to health problems associated with a lack of physical activity. Additionally, the repetitive movements of robots pose new emerging risks related to collisions or entrapments when humans are nearby (Arana-Landín et al., 2023; Lemos et al., 2022).

Moreover, the close interaction between employees and cobots in environments designed to support complex and dangerous tasks raises safety concerns. Employees uniquely possess the flexibility and problem-solving skills to address and overcome these challenges when production line disruptions occur, whether due to technical malfunctions, supply chain issues, or unforeseen circumstances (Moore, 2019). These robots must be equipped with complex programming to distinguish and avoid actions that could harm employees. Ensuring safe and effective human-robot collaboration requires the development of safety-conscious robots that can understand the intentions of employees in their vicinity (Badri et al., 2018).

The shift to more technologically advanced workplaces also creates organisational and psychosocial challenges. The pressure to meet production targets in collaboration with robots can force employees to work unreasonably fast, leading to increased stress and potential burnout. This pressure is compounded by the lack of social interaction in highly automated environments, which can negatively affect employees' mental health (European Agency for Safety and Health at Work, 2019; Moore, 2019).

The demands of new technologies further challenge employees' mental health. Workplace stress can increase due to continuous employee monitoring, rising productivity expectations, the need to work outside regular hours, and the frequent learning of new systems. The lack of human interaction, coupled with insufficient workforce consultation during the implementation of new technologies, can lead to a rise in mental health-related issues and compensation claims (Horton et al., 2018).

Additionally, the rapid reconfiguration of work processes in response to consumer demands for customization can lead to frequent changes in a factory's risk profile. This constant flux makes it challenging to standardize OSH procedures, conduct consistent risk assessments, and manage other safety aspects effectively (European Agency for Safety and Health at Work, 2018).

Challenges typically stem from issues related to technology, such as software and hardware or availability, humans, like resistance to implementation or lack of technological skills, and organisational factors, including the need for adjustments in a structural level, problems identified during the planning process, and financial constraints (European Agency for Safety and Health at Work & Future Impacts., 2023). Successfully navigating these challenges during the transition from traditional to advanced technological work environments requires careful management and a balanced approach to the application and oversight of these technologies.

To address these challenges, robots that prioritise safety, identify potentially hazardous actions and understand employees' intentions need to be developed (Badri et al., 2018). Additionally, companies must adjust their OSH policies to accommodate this new reality, proactively addressing the emerging risks (Lemos et al., 2022).

Industry 4.0 technologies offer significant advantages for the food sector, including improved efficiency, sustainability, and innovation, considerable barriers remain to their implementation. To unlock the full potential of these technologies, challenges must be addressed through strategic financial support, compliance with regulations, skill development, and proactive management of ethical issues.

Regulatory Landscape and Ethical Considerations

1.7 European Policies in Digitalisation, Automation and AI

This subchapter will be done in v2 of the deliverable.

1.8 National Regulations in Spain, Portugal, Italy and Belgium

The regulatory framework in Europe actively shapes digitalisation, automation, and AI in the food industry, influenced by national efforts and European Union (EU) policies. Every country has its approach to implementing these technologies in the food industry, which often aligns with regulations set by the EU.

Spain established the Spanish Agency for the Supervision of Artificial Intelligence (AESIA) to enforce AI standards, particularly in businesses involving personal data, such as the food industry. This aligns with Spain's National Artificial Intelligence Strategy, which prioritises inclusive and sustainable AI development (Quathem, 2023).

Portugal's AI policy aims to promote AI applications in the public and private sectors. It entails establishing testing facilities and innovation sandboxes to promote technological developments in the food industry (European Commission, 2021b).

Italy's National AI Strategy focuses on ethical regulatory frameworks for AI to promote openness and responsibility. To improve competitiveness and sustainability, the policy calls for integrating artificial intelligence into numerous industries, such as food and agriculture (European Commission, 2020).

Belgium promotes digital innovation in the food industry with initiatives such as S3FOOD, which assists small and medium-sized enterprises (SMEs) in adopting smart sensor technology for increased energy efficiency and sustainable manufacturing (European Commission, 2022).

At the European level, the Digital Europe Programme seeks to improve digital capacity in essential industries, including agricultural production. This initiative promotes the development of new technologies, such as artificial intelligence and cybersecurity, which are critical for modernising the food industry (European Commission, 2024).

This subchapter will be finalised in v2 of the deliverable with the help of the Pilots.

1.9 Standardisation in Industry 4.0 Technologies

This subchapter will be done in v2 of the deliverable.

1.10 Safety and Health Policies in Digitalisation, Automation

European policy on safety and health in the context of digitalisation, automation, and AI aims to address emerging risks, mitigate or control psychological and physical risks, and prevent new forms of risk. It also promotes inclusion, fosters adaptability, and ensures balanced productivity, employee safety, and well-being.

Policies that properly manage the opportunities and challenges presented by robotic systems and AI-based technologies can enhance OSH outcomes by maximizing benefits and minimizing risks (European Agency for Safety and Health at Work, 2022a).

Awareness and understanding of the existing regulations and policies ensure that proposed projects comply with legal requirements and best practices. At the same time, companies can voice their challenges and advocate for necessary regulatory adjustments or innovations to address emerging needs (European Agency for Safety and Health at Work, 2023).

External barriers to the effective integration of digitalisation, automation and AI-based technologies include the current state of legislative frameworks (European Agency for Safety and Health at Work, 2023). Labour and occupational safety and health laws have failed to adapt to the rapid emergence of new technologies and their safe integration, leaving OSH with limited guidance (European Agency for Safety and Health at Work, 2018; Moore, 2019). The European Commission proposed the AI Act 2021 to address these gaps, aiming to harmonise AI-related rules across the EU. It is designed to protect fundamental rights and ensure public confidence in AI systems. Additionally, steps are being taken to establish a European AI Board to facilitate regulation implementation across Europe, alongside a public database for high-risk AI systems (European Agency for Safety and Health at Work, 2022b).

“EU Strategic Framework on Health and Safety at Work 2021-2027” and the “European Framework Agreement on Digitalisation” provide a framework for integrating safety and health considerations into deploying digital, automated and AI-based solutions while safeguarding employees’ well-being. “The EU Strategic Framework on Health and Safety at Work 2021-2027” focuses on three objectives: managing changes brought by digitalisation, improving the prevention of workplace accidents and illnesses, and preparing for future health crises. Emphasises that healthy working conditions are essential for a productive workforce and fundamental to achieving sustainable development goals (European Commission, 2021a). The “European Framework Agreement on Digitalisation”, signed by social partners, highlights the need to manage work-life boundaries and ensure that AI systems adhere to the “human in control” principle. It seeks to protect human dignity and address potential surveillance risks through transparent data processing (European Social Partners, 2020).

The Machinery Directive and the Work Equipment Directive 2009/104/EC have been criticised for not sufficiently matching the current state-of-the-art technologies (European Agency for Safety and Health at Work, 2023). Regulation (EU) 2023/1230 on Machinery has replaced the previous Machinery Directive. This new Regulation, set to take full effect on 20 January 2027, seeks to address these shortcomings by providing a more comprehensive and adaptable framework that aligns with technological evolution.

AI's implementation raises several concerns that must be addressed through effective regulation. Privacy violations, lack of transparency, accountability gaps, intrinsic bias, and the potential depersonalisation of social interactions must be addressed. The "human in control" principle emerges as a guideline ensuring that humans maintain authority over AI-driven decisions at various levels, from individual interactions to organisational policies. Transparency is equally important, requiring that the capabilities and limitations of advanced systems be explained to users, fostering trust and accountability across organisational structures (Rosen et al., 2022).

Specific legislation targeting AI-based systems and OSH is currently lacking, though existing legislation covers OSH issues at some level when referring to AI-based systems and robotic systems (European Agency for Safety and Health at Work, 2022b). This reflects on specific fields, such as chemical risks, that must be updated (Tepe, 2021). The rapid pace of technological change can hinder the ability to provide OSH research and regulations on time to apply them in companies (European Agency for Safety and Health at Work, 2018).

Many countries work on non-legally binding initiatives, campaign programmes, guidelines, or recommendations to address AI-related OSH concerns. Moreover, the global interconnectedness of AI systems can make national-level regulations impractical. A fragmented regulatory approach would create significant administrative complexity and financial burdens on international businesses, complicating compliance and encouraging regulatory arbitrage. To ensure employee protection on a global scale, effective AI workplace regulations demand collaborative, cross-national strategies that develop harmonised standards transcending individual national interests (European Agency for Safety and Health at Work, 2022b).

Finally, OSH risks associated with AI systems can be difficult to detect, particularly the ones related to cognitive risks such as increased stress. Policymakers and regulators should not ignore these long-term risks to employee safety and health (European Agency for Safety and Health at Work, 2022b).

1.11 Ethical Considerations and Data Privacy

The European Commission actively develops ethical and safety norms for AI and digital technologies, especially in the food industry, where automation and data processing are becoming more common.

The General Data Protection Regulation (GDPR) establishes a foundation for *data privacy* in the EU, demanding that companies handle personal data with care and transparency. This legislation applies to all industries, including the food business, where digitisation necessitates extensive data gathering and processing. The GDPR requires rigorous compliance to safeguard customer data from abuse and unauthorised access (European Commission, 2024).

The European Commission emphasises the importance of *ethical AI* that is transparent, responsible, and consistent with fundamental rights. The Commission aims to set guidelines to ensure AI systems do not propagate prejudices or violate personal rights. This is especially important in automated food systems, where choices might influence consumer health and safety (European Commission, 2024).

The EU has introduced measures such as the Machinery Directive to guarantee that automated machinery fulfils stringent *safety requirements* in industries such as food processing. These guidelines prevent mishaps and guarantee automated systems' secure and effective operation (European Commission, 2024).

The European Commission's all-encompassing strategy for digitalisation in sectors like food processing ensures that technological advancements are balanced against ethical considerations and strict safety rules.

This subchapter will be finalised in v2 of the deliverable with the help of the APQ partner.

Human Factors

Human factors are an interdisciplinary field that examines how people interact with systems, products, and environments. The primary goal of human factors is to enhance safety, efficiency, and user satisfaction by integrating cognitive, physical, and social dimensions of human behaviour into system design (Lee et al., 2017). Human Factors combines anthropology, engineering, and psychology to create user-centred and flexible systems by considering human strengths and weaknesses (Karwowski & Zhang, 2021; Spath & Braun, 2021).

Human factors in organisational settings analyse the interactions of individuals and groups as industries adjust to fast technological progress such as automation and AI. Recognising human factors is essential for comprehending digital transformation's social and cognitive effects, as these technological advancements impact tasks, employee involvement, managerial strategies, and organisational culture. Integrating automation with human expertise is crucial in industries which heavily depend on digital technologies. Human factors techniques in such domains entail reorganising processes to guarantee the smooth integration of automation and digital technologies into human operations, increasing productivity and well-being (Spath & Braun, 2021).

This approach enhances usability and guarantees that technology is designed to support. This has led to a need for system designs that focus on ergonomics and user experience. Implementing human factors concepts successfully in such circumstances increases human resource sustainability, lowers physical and cognitive demands on employees, and creates a safer, more efficient work environment (Karwowski & Zhang, 2021; Lee et al., 2017; Spath & Braun, 2021). As a multidisciplinary framework, human factors provide a comprehensive approach to creating and deploying technology that addresses human requirements while improving organisational performance.

1.12 The Role of Human Resources in Digital Transformation

1.12.1 Change Management

Change management is essential for effectively navigating organisational transitions, particularly digital ones. With the support of this systematic strategy, companies may improve their company by implementing significant internal changes (Kitchen & Daly, 2002). These modifications may take the form of significant shifts in the offer, technological improvements, or even modifications to the organisational structure.

Digital transformation transcends a trend in today's quickly changing corporate environment. Change management's significant goals are to embrace unexpected opportunities, negotiate the introduction of new technology, and change consumer contacts with businesses.

In Industry 4.0, good change management pivots on a systematically planned digital transition. One cannot underline the role that leadership plays in managing change. Leaders must clearly express their transformation aim and actively involve staff members to build loyalty and reduce resistance (Hartge et al., 2019).

Any opposition to the change might hamper efficient transitions, hence the importance of knowledge of innovation and arming management with creative training (Petrillo et al., 2018). Clearing the misunderstandings about the expenses and subtleties of bringing industrial robots into the food industry demands conscious effort (Bader & Rahimifard, 2018). Companies must create well-rounded strategies considering the steps of the transformation process to allow for a perfect digital transition.

Overcoming resistance to change is a primary challenge during digital transformation. HR departments must develop strategies to address this resistance, providing tools, training, or other help to allow staff members to adopt new technology and processes (Ancarani & Di Mauro, 2018). It is crucial to create comprehensive plans to guide the business through the transformation process (Ghaani et al., 2016). Equally important is the need for honest and open communication with employees as it would help them to understand the reasons behind the changes, their prospective benefits, and how they will influence specific roles and responsibilities (Proctor & Doukakis, 2003). Motivating the acceptance of new technologies and processes relies on creating an inventive and constantly learning culture within the organisation (Ancarani & Di Mauro, 2018).

Guaranteeing that staff members have the required abilities to flourish in technologically evolved surroundings depends on addressing the growth of competencies. This means spotting areas of weakness and beginning focused training initiatives to inspire flexibility and lifelong learning (Cirillo et al., 2021). Including these components in a complete change management plan helps businesses raise their possibilities of managing the complexity of digital transformation.

Kotter's 8-step change model (1996) is a well-known tool for handling organisational change (Appelbaum et al., 2012). There are eight separate phases to the approach, starting with *raising awareness*. This first stage raises awareness of the necessity of change by assessing the company's market position and competitive scenario. Kotter underlines that initiatives for change are likely to take off with a strong feeling of urgency.

The *building of a leading coalition* comes second. Kotter contends that a coalition of influential people is required to propel the change, as no person can lead change by itself. This alliance should have enough force to guarantee that the transformation process is not hampered.

The third phase involves *formulating a vision and a plan*. A clear, appealing vision guides the transformation process. This vision offers a structure for decision-making and aligns the company's efforts.

The fourth phase outlines the *vision for transformation*. Ensuring all stakeholders grasp the goal and the causes behind the change. These depends on good communication. Kotter advises spreading the information frequently by utilising many communication channels.

The fifth phase of the model encourages *wide-based activity*. This phase entails clearing roadblocks that are preventing the change and arming staff members to be proactive. To enable employee involvement, Kotter emphasises removing structural and supervising obstacles.

In the sixth phase, *creating temporary gains* takes centre stage. Building momentum and proving that the change effort produces outcomes. These is obtained by celebrating small successes. These victories support dedication to the transformation process.

The seventh stage is *compiling gains and generating additional change*. Building on initial accomplishments is essential for overcoming future challenges. Declaring success too early runs the danger of encouraging complacency, Kotter advises against.

Anchoring fresh methods in the company culture comes last in the model. Sustainable changes must be included in the company's culture. This entails proving how different behaviours enhance performance and ensuring that future leaders reflect these developments.

Kotter's approach is flexible, even if it has been somewhat influential. Critics contend that its strict sequential method may not be appropriate in every situation, and specific actions might not be pertinent for changes (Appelbaum et al., 2012). Notwithstanding these objections, the model is nevertheless a valuable tool for managers applying change successfully (Appelbaum et al., 2012). An articulated vision encourages staff involvement and uses different abilities when successfully turned into operational goals (Ancarani & Di Mauro, 2018).

The success of change management initiatives depends on open and honest communication. This method clarifies for staff why the change is occurring, its advantages, and how it will influence their employment. When introducing new automated systems, it is imperative to fully explain any changes. Past automation experiences may help individuals to be more receptive to more recent and sophisticated forms of automation (Bekier & Molesworth, 2017). When combining AI, automation, and digitalisation, a communication plan for managing change is crucial. This strategy focuses on nurturing open and honest communication during the change process.

Companies must communicate the reasons for change, showing how embracing new technologies will benefit the organisation and its people. This openness fosters a sense of understanding and support among everyone involved. Being open and transparent is essential for fostering understanding, and good communication can reduce resistance and enhance involvement (Neill et al., 2020).

Creating formal and unofficial channels of communication is a very vital strategy. Using emails, newsletters, intranets, and social media channels, companies may interact with every employee from several angles. These channels let employees discuss ideas, voice worries, and review their experiences throughout the transition. This conversation might provide perceptive analysis and progress in current technological applications. A warm and inclusive communication atmosphere helps to develop exemplary employee dedication and embrace of change. Honest communication promotes discourse and feedback, involving individuals and enabling quick solutions to challenges. These communications help alleviate concerns and clear up misunderstandings about new technologies. Strategies such as town hall meetings, employee ambassador programs, and culture committees (Neill et al., 2020) help significantly improve a culture of feedback.

Companies should include redundancy in their communication initiatives (Klein, 1996). Repeating key ideas across many platforms helps to enhance the narrative of change, facilitating memory and acceptance of vital knowledge (Klein, 1996). Regularly emphasising key messages allows people to understand and remember the communicated changes. The initial message regarding change often falls short of what people hope for, resulting in uncertainty and frustration among team members (Frahm & Brown, 2007). This emphasises how important it is to use sensible communication techniques.

A good communication strategy relies on education and training. Offering training that allows employees to understand new technologies and processes, helps explain the changes and motivates their confidence in adapting. One way to reduce resistance to change is to develop skills actively. In this sense, sensitivity training, which aims to customise some corporate changes, can also be helpful (Katz & Kahn, 2015). Good sharing of changes relies on honest conversation and open expression. Using our common difficulties and strategies to overcome them helps us to establish confidence and trustworthiness. Transparency and openness help to set expectations and show the organisational will to help staff members through the change.

The approach of Klein (1996) highlights the need to involve leaders. These influential individuals may support the path of transformation and aid in creating a good view of change. Firm support helps staff to accept new technology with great enthusiasm.

Leaders can communicate in five unique ways, hope orientation, reality orientation, subordinate orientation, support orientation, and imposition orientation, to genuinely address employee concerns (Luo et al., 2016).

Hope orientation focuses on inspiring hope about the accomplishment of the transformation project. Leaders who use hope-oriented communication try to allay subordinates' worries about the change's failure by projecting a favourable view of its possible results. This approach has dramatically enhanced subordinates' emotional commitment to change.

Reality orientation offers all-encompassing, objective knowledge about the shift. This approach guarantees that subordinates are entirely informed about the advantages and drawbacks of the change, therefore addressing their worry about only partial knowledge. On emotional commitment, the research revealed that reality orientation has a negative but little impact.

Subordinate orientation helps subordinates overcome their loss anxiety by stressing the advantages of change. Leaders using a subordinate-oriented communication approach are likelier to raise their subordinates' dedication to change as it emphasises how change may benefit them.

Support orientation ensures that subordinates feel the leader is committed to helping them through the transformation process. This approach is crucial for alleviating anxiety about inadequate support and has been proven to increase emotional commitment.

A newly discovered feature, *imposition orientation*, entails more authoritarian communication techniques, which would be more common in societies with more significant power distance, as in Chinese companies. It is characterised by dominating and authoritarian communication styles. Nonetheless, it was shown to have no appreciable influence on emotional commitment.

Open conversations can help reduce organisational resistance, promote genuine involvement, and create a space where dialogue can thrive (Simoes & Esposito, 2014). Resistance can come from various factors, like a lack of trust, a culture of secrecy, insufficient skills, limited resources, and the lack of a unified strategy (Daly et al., 2003). The approach to internal communication emphasises the importance of engaging employees and fostering a culture of openness within the organisation.

Effective management of change depends on clear responsibilities. Clarifying the new tasks and obligations accompanying automation helps employees understand their place in the altered workplace (Klein, 1996). This clarity will assist in easing worries about prospects and job security.

It is essential to include employees in the change process. People involved in planning and implementing processes rely on their knowledge and insights while fostering a sense of ownership and commitment to the changes (Klein, 1996). Including people in this process helps to reduce resistance and increase the probability of a positive outcome.

Recognition and celebration of achievements are vital sources of inspiration. Emphasising even little achievements might help one to feel forward and inspire continuous support for change (Klein, 1996). These festivities may brighten the good features of the change and raise enthusiasm. These aspects show how various communication approaches may help overcome specific concerns related to organisational change, affecting employee commitment to the change process (Luo et al., 2016).

It is also essential to consider gradual changes. This strategy allows companies to satisfy the sector's changing demands more successfully and helps minimise layoffs. Companies prioritising skill development and staff training stress the need for these procedures (Cirillo et al., 2021). Improved skill sets help a team be more ready to accept digital technology effectively.

Many experts believe that systemic changes are the best way to transform human companies, as they directly affect different aspects of these companies (Katz & Kahn, 2015). We can create more meaningful changes by examining how decision-making power is shared and ensuring that our social and technical systems work together. Kurt Lewin's Change Management Model, often called the Unfreeze-Change-Refreeze model, offers a distinctive perspective on navigating organisational change (Appelbaum et al., 2012). The model consists of three distinct stages.

The *Unfreeze Stage* is the first step in companies' taking a good look at their current situation and sharing why change is necessary. A food industry organisation may examine its present procedures more closely and find places where automation might increase effectiveness (Appelbaum et al., 2012). In this phase, open communication and training possibilities help resolve issues like worries about job loss through development. This stage is essential for enabling the company to welcome change and inspire a readiness to move from the present state.

The second *Change Stage* is carrying out the intended improvements under the direction of necessary staff training and assistance. For example, businesses in the food industry desiring to use artificial intelligence systems may start small-scale trials to show the advantages before starting a large-scale deployment (Appelbaum et al., 2012). Improving processes and managing new problems relies on continuous feedback, assuring staff assistance during the transformation.

The *Refreeze Stage* confirms the improvements spun into the operations and culture of the company. Following effective modifications, companies must track performance indicators to ensure the gains hold throughout time (Appelbaum et al., 2012). This stage guarantees that our adopted changes have become a constant feature of our company's everyday activities and culture. After effective modifications, businesses must monitor performance indicators to ensure these gains persist throughout time (Appelbaum et al., 2012). Regular training, compliments on successes, and continuous support help new routines and habits to be reinforced. These components help staff members fit the new system and easily incorporate schedule changes. Bringing improvements into the organisational culture helps produce long-lasting transformation, reducing the likelihood of returning to previous practices.

Successfully managing change in the digital transformation of the food industry requires a comprehensive and diverse approach. Recognising that an effective communication, a clear explanation, ongoing training, and solid leadership support are vital in overcoming resistance and ensuring the smooth adoption of new technologies. Models such as Kotter's 8-Step Change Model and Lewin's Unfreeze-Change-Refreeze could provide helpful guidance as businesses navigate the complexities of change management.

1.12.2 Changes in Roles and Competence Development

When companies introduce new technologies, it results in alterations in the roles and responsibilities of employees. Emerging tools and processes in the context of Industry 4.0 influence the transformation of conventional roles. Automation changes traditional responsibilities through consistent and precise work completion. From this change, new jobs and knowledge have evolved as robots and automated systems can now do activities that used to be made by humans.

The emergence of new jobs and specialisations increasingly emphasises Industry 4.0 and digital transformation framework. Integrating cyber-physical systems and changing production processes requires a more all-encompassing spectrum of competencies. This shift requires staff who can work in teams to manage technical challenges about complex production systems (Madsen et al., 2016).

Under human-robot collaboration (HRC), the focus is on shifting roles and responding to new technologies and practices. Using HRC requires staff members to communicate with numerous technologies, including augmented reality, voice, gesture recognition, and laser projection of cutting trajectories. Combining these technologies improves the interaction and cooperation between people and robots in professional environments, transforming traditional roles and generating the rise of new competencies (Romanov et al., 2022).

With the introduction of big data business analytics (BDBA) new roles and expertise are being developed. Companies must create a new vision by integrating BDBA into their daily operations and fostering a culture prioritising data-driven decision-making. The shift to data-driven operations calls for the development of new roles and specialisations meant to control and analyse the vast amounts of data (Ancarani & Di Mauro, 2018).

The digital revolution in many areas has generated significant shifts in roles and responsibilities. We are experiencing a complicated mix of changing conventional roles, the emergence of new positions and specialities, and the need to adjust to creative tools and techniques. The workforce needs to change with new skills and competencies learning to sufficiently tackle the issues of the digital age as companies adopt Industry 4.0 technologies.

Companies must continually enhance their employees' capabilities to help them with the changes and introduction of new roles. Understanding the skills gap helps create focused training programs that address these shortcomings and encourage ongoing learning and flexibility.

Companies that invest in thorough training courses usually produce a more competent staff, improving their capacity to embrace new digital technologies (Cirillo et al., 2021).

The shift to Industry 4.0 technologies calls for a spectrum of competencies, combining technical experience, digital skills, flexibility, problem-solving, creative thinking, critical thinking. collaboration, communication skills, knowledge of safety processes, and a strong sense of ethics (Akyazi et al., 2020; Andriole, 2018; Jurczuk & Florea, 2022; Martin, 2018). This all-encompassing approach guarantees the expansion of the workforce in a society that relies more on technology and automation. It allows for managing the problematic issues of digital transformation in the food industry.

Technical knowledge is essential for maintenance and troubleshooting (Andriole, 2018), employees must be equipped with the necessary abilities to maintain the equipment effectively and smoothly. Understanding robotics, automation, and AI enables the seamless integration of these technologies across various processes (Akyazi et al., 2020; Andriole, 2018).

Digital skills are essential, for a employee that as the role of using and maintaining innovative packaging technologies, often including sensors (Akyazi et al., 2020).

All employees must be *flexible* to learn about the newly developed technology and procedures. Employees must participate in reskilling and upskilling efforts to keep up with the latest technological changes (Akyazi et al., 2020; Andriole, 2018). This involvement shows a willingness to embrace change and highlights the ability to adjust to new tools and methods. The capacity to participate in critical thinking and problem-solving is crucial in today's fast-changing terrain.

Problem solving is a fundamental skill in the 21st century, essential for professional success. While creativity drives innovative ideas, problem-solving skills enable workers to analyse complex issues, develop creative solutions and implement them effectively.

While *creative thinking* is essential in generating fresh solutions to complex problems (Akyazi et al., 2020; Andriole, 2018), *critical thinking* enables people to make informed decisions depending on facts and fresh ideas. Dedication to the continuous growth and support of a knowledgeable and adaptable society is essential.

Teamwork and *collaboration skills* are crucial for succeeding in Industry 4.0 (Akyazi et al., 2020). They are crucial elements for organisational success in the modern workplace. While teamwork involves coordinating individual efforts to achieve common goals, collaboration goes further, promoting synergy and the co-creation of innovative ideas. The effectiveness of these practices depends heavily on open communication, mutual trust and respect between team members.

Practical *communication skills* are essential for clearly sharing technical information and promoting successful project teamwork (Akyazi et al., 2020). Additionally, working well in diverse teams relies heavily on collaboration among different fields.

Employees must have *knowledge on safety*, they must be well-informed on safety procedures to assisting in stopping, evaluating and reducing risks (Andriole, 2018).

Employees must have a *strong moral and ethical sense* about the issues of using digital technologies and AI. Sensibly using technology relies on understanding this idea as it safeguards the welfare of our society, privacy, and security.

After the key competencies have been identified, creating and implementing practical training courses is next on the path of digital transformation. Usually, the technology provider will provide the necessary training when new technologies like robots or automated systems become relevant. This method helps employees weave learning into everyday activities, nurturing a culture of ongoing education and flexibility (Lloyd & Payne, 2023).

Introducing digitalisation, automation and AI requires a well-rounded training programme to help everyone adapt and successfully implement these new technologies. Start by assessing what training is needed, checking how ready the organisation and its employees are, and determining the necessary new skills. The initial assessment is crucial in customising training programs to address the workforce's needs.

Creating a supportive and encouraging educational environment involves discussing planned changes with employees and clarifying their intended purpose. Creating a transparent and open environment enables businesses to communicate the value of changes, inspiring employees to participate in the training programme (Kirkpatrick & Kirkpatrick, 2006). Furthermore, encouraging a learning culture among the employees depends on trainees having the correct attitude. Encouragement of this point of view helps individuals accept fresh information and abilities as they negotiate the complexity of digital change.

Achieving good training results depends on correctly using instructional strategies. To improve the learning process, companies should provide unambiguous information, practical examples, and plenty of opportunities to practice. Direct engagement of staff members via practical training enables them to experience the new tools and systems introduced (Kirkpatrick & Kirkpatrick, 2006). This practical technique significantly improves professional retention and implementation of fresh skills.

Helping employees transfer their training is crucial, as it means addressing the challenges that might stop them from using the new skills they have just learnt. Companies should create an environment that fosters the use of skills, motivating employees to bring their acquired knowledge into their everyday work (Salas et al., 2012). Evaluating the effectiveness of training is what truly matters. Connecting evaluations to the specific training needs identified is essential to see how these programs influence employee performance (Salas et al., 2012).

A nurturing environment after training helps deepen understanding and encourages ongoing growth. Maintaining motivation and enabling people to implement the freshly gained abilities depends mostly on peer support and improved supervision (Salas et al., 2012; Westerman et al., 2014). Constant communication is vital throughout the training as open channels enable staff members to feel informed and encouraged.

Leadership is essential in guiding the success of training programs. Companies ought to set a positive example by prioritising the training of their leaders. This shows a genuine commitment to change and fosters a culture of learning that starts at the top and influences everyone below (Salas et al., 2012; Westerman et al., 2014). Safety and compliance must first take the front stage during the training process.

Emphasising the benefits of digitalisation and automation will help to enhance staff interaction with training courses. When businesses present the benefits of new technology, their employees might be inspired to welcome the changes (Westerman et al., 2014). Moreover, it is also essential to create settings that support intellectual engagement and collaboration. Encouragement of cooperation helps employees gain from one another and share their experiences, strengthening the team and raising its competence (Westerman et al., 2014).

Successful management of digital developments in the food industry depends on developing and executing training programs after discovering new capabilities. Companies that invest time in knowing their training requirements, create a friendly learning atmosphere, encourage a good attitude among their staff members, and use successful teaching strategies will be ready to equip their staff members to meet the challenges presented by new technologies (Salas et al., 2012; Westerman et al., 2014). Improving continuous learning and adaptation by employing a culture enabling regular review, compassionate surroundings, and committed leadership can help provide better digital integration results (Salas et al., 2012).

Good management of digital transformations depends on constant learning and adaptation. Giving HR management great attention would promote technological development via HR activities, thus properly guiding the transition to Industry 4.0. Employees are the most flexible aspect of this changing system (Mijatović et al., 2020). Initiatives supported by the government that promote sustainable business practices and encourage collaboration and innovative thinking play a crucial role in building an environment that nurtures continuous learning and adaptability (Annosi et al., 2020).

The food industry's shift to Industry 4.0 calls for an all-encompassing strategy for staff skill development and education. Companies must identify skill shortages, design successful training courses, provide a friendly learning atmosphere, and use compelling teaching approaches. Promoting a culture of lifelong learning depends much on leadership. Nonetheless, stressing safety, compliance, and the advantage of digitalisation comes first.

1.12.3 Talent Engagement

HR in the modern setting mainly concentrates on keeping and involving employees, particularly amid digital changes. Companies increasingly realise the value of digital skills, so they include staff members in significant development initiatives and support an innovative culture and constant learning. Attracting personnel with digital expertise might prove challenging for companies just beginning their digital transformation road.

Companies that desire top talent in digital technologies must show their commitment to innovation and professional development opportunities in technologically advanced surroundings. Effective recruiting strategies depend on knowledge of social cognition, which enables companies to customise their message to the objectives and initial impressions of possible workers (Fiske & Taylor, 2017). This approach emphasises the company's technical developments and shows how these ideas support a dynamic and exciting workplace.

Companies that attract competent personnel and provide significant training courses are more open to employing fresh digital technology (Cirillo et al., 2021). This underlines the need for HR to offer skill development and training as a top priority, as they are required for correctly employing digital technology. Companies must attract and retain those with the required digital skills to use these technologies correctly.

Effective people management in today's digital environment depends on including staff members in tailored development programs. Programmes for well-structured development stressing ongoing education and skill development help to increase retention rates. Our learning experience mainly relies on motivation. So, it is essential to underline that companies must provide an environment where employees may pursue personal growth (Weiner, 2012). These programs provide access to online learning systems specialised to help workers' professional aims, mentorship opportunities, and fascinating seminars, thus promoting loyalty and lowering turnover rates. Frequent assessment of training requirements guarantees they complement the approaches for adopting digital technology. This approach keeps staff members interested and prepares them for upcoming technology developments (Achtenhagen & Achtenhagen, 2019). Likewise, companies can give customised training from technology vendors when introducing new digital technologies like robots and automated systems. This approach weaves learning into daily activities so that people routinely improve their skills to meet evolving demands (Lloyd & Payne, 2023).

Maintaining the involvement and dedication of exceptional individuals requires an environment that fosters innovation. Aiming for a harmonious middle ground, the Optimal Distinctiveness Theory states that people strive to balance membership with uniqueness (Brewer, 2011). Companies should create environments where employees feel inspired to share their innovative ideas and have the means to examine and back up these ideas. This creates a welcoming environment where employees might be who they are—something crucial for a hectic workplace. Organisations undergoing digital transformation must foster a strong culture of innovation and learning. Engaging staff members and improving organisational agility depends on urgency surrounding digital projects as they generate momentum for change (Ancarani & Di Mauro, 2018).

Incorporating big data business analytics into organisational processes fosters a culture where data insights guide decisions. This approach centred on data, encourages innovation and continuous learning as employees incorporate analytics-driven tools and processes into their daily routines (Ancarani & Di Mauro, 2018). Encouraging an environment that values innovation and ongoing education is essential for effective digital transformation. Government initiatives promoting sustainable business models through teamwork and open-minded innovation emphasise this critical need. This insight, aimed mainly at policymakers, highlights the crucial role of organisations in nurturing a culture that appreciates learning and encourages innovation (Annosi et al., 2020).

In today's digital landscape, drawing in and keeping talent calls for a thoughtful and comprehensive approach. Organisations must focus on bringing in people with digital skills and creating important development programs to engage this talent. Creating a space that values creativity and continuous learning is also essential. By focusing on these elements, organisations can foster a strong workforce that adapts to technological changes while encouraging sustainable growth and innovation.

1.13 The Impact of Digital Transformation on Employees

1.13.1 Impact on Different Employees

The continuous digital revolution of many industries has significantly impacted many workers, particularly older workers and those with fewer qualifications. Furthermore, the dynamics of gender roles in specific industries, including the food industry, can be quite perplexing. Companies must face these changes using plans to counter technological resistance, mentoring programs, retraining programs, and gender-inclusive strategies, unique opportunities and challenges offered by which these advancements affect them.

Older workers with less experience may need help to adapt to the rapid advancements in digital technologies. Their inability to use contemporary methodologies raises concerns over their potential to fulfil current technical demands. This issue may adversely affect their productivity and workplace well-being (Hassoun et al., 2023). People with less education might feel overwhelmed by the growing demand for digital skills (Lloyd & Payne, 2023). With proper training, they can avoid losing their jobs. The shift towards automation and digital tools in industrial environments can pose difficulties for individuals less comfortable with technology when learning new skills (Asiati et al., 2018).

Thus, companies are gradually launching retraining and help programs to equip these workers with the tools needed for success in the digital age. Customised training seminars, self-paced online learning, and on-the-job training (Caldwell, 2012; Petrou et al., 2018) are strategies to smooth the adjustment and increase confidence in using new technologies. These approaches assist employees in developing their abilities and lower the stress sometimes related to conventional classroom environments.

Overcoming resistance to technological change depends on including staff members in deploying new technology. Encouragement of staff members to accept responsibility, involvement, and inclusion helps reduce resistance and considerably helps bring about change (Hassoun et al., 2023). Mentoring programs and peer support systems help this change by providing direction and a feeling of belonging. These networks are crucial in challenging production environments since cooperation increases individual and general worker resilience (Madsen et al., 2016; Simoes & Esposito, 2014). Since new technologies transform the industry, it is essential to analyse how they affect worker relations and gender equality.

Like many others, the food industry has traditionally set itself apart with gender disparities in various roles and leadership positions. New technologies, however, are altering the required skill sets and job roles, either widening or helping to reduce this gap. Advanced technologies in the food industry enhance traceability and transparency, creating equal opportunities for all stakeholders involved (Sharma et al., 2024). Guaranteeing women have equal access to training and development in these new industries. This technology development presents an opportunity to solve gender disparity.

Despite hope for good change, some concerns arise about how the digital revolution could disproportionately impact working women. According to the United Nations, for every job men gain, women will lose five during the Fourth Industrial Revolution (UNESCO, 2021). This discrepancy underlines how necessary regulations guaranteeing women's equal access to education and skill development will help them be equipped for future jobs in the food industry.

Numerous sectors, including the food sector, are addressing these problems in different ways. Strategies such as mentoring programs, flexible work hours, and specialist training courses help women respond to the fast-changing technological scene (Sharma et al., 2024). These projects aim to make the surroundings more friendly and equip women to succeed in a technologically evolved food industry.

Research shows the financial opportunities of closing gender disparities in technologically driven industries. By closing the gender gap in education and work, the GDP throughout the EU will be raised (UNESCO, 2021). Digitalisation and automation offer opportunities in the food sector to rethink workplace cultures and promote diversity, fostering innovation and sustainability.

Businesses wanting to take advantage of these possibilities must follow thorough plans. A balanced workforce will emerge by promoting diversity, encouraging women to pursue data science and food technology careers, and providing mentorship opportunities. Achieving justice in the changing food industry requires flexible work norms and accommodating caregiving needs (Jejeniwa et al., 2024).

The ongoing digital revolution has dramatically affected senior employees with less education and the changing gender roles in the workplace. Organisations should create well-rounded strategies that embrace mentoring, inclusive decision-making, gender-sensitive policies, and tailored training to tackle these challenges effectively. By tackling inequality and nurturing an inclusive workplace, the food and other industries can strengthen their teams, encourage creativity, and reach their Industry 4.0 aspirations.

1.13.2 Psychological and Behavioural Impact

The digital transformation in the food industry has caused notable psychological and behavioural changes for employees. New technologies and methods used by businesses often cause stress and anxiety among employees. Effectively managing this stress will determine the success of the digital transformation.

Affective Events Theory (AET) clarifies how this change affects job satisfaction and the emotional experiences of those working in the food industry (Weiss & Beal, 2005). AET emphasises the role that workplace events play as proximal triggers of emotions. Including new technology in the food industry is an important event triggering emotional responses among employees.

Personal reactions to these technological innovations vary greatly. While some employees would be happy and eager to learn new skills and increase performance, others may be concerned or unhappy about the challenges of transitioning to different systems. As AET suggests, these emotional experiences might have immediate and transient effects on behaviour, potentially influencing short-term output (Weiss & Beal, 2005).

In this context, the distinction between affect-driven and judgment-driven behaviours of the theory is relevant. Instantaneous emotional responses to events linked to digital transformation might result in affect-driven activities like more significant contact with new technologies or resistance to change. These events build up over time to affect workers' general job happiness, affecting their judgment-driven actions, including long-term loyalty to the company or choices on career development in the technologically changed food business (Weiss & Beal, 2005).

Good stress and anxiety management primarily depends on good communication. Effective and honest internal communication that lets staff members grasp the objectives, policies, and reasoning behind organisational changes can help share knowledge about them (Proctor & Doukakis, 2003). This strategy would assist in reducing staff worry and uncertainty. People's emotional reactions to change are much influenced by their assessment of a given scenario (Fiske & Taylor, 2017).

Companies should use change management strategies, such as open communication about the changes, training opportunities, and support systems, to effectively moderate employees' emotional reactions. Workers' personality traits usually define their thoughts towards modern technology. Understanding the psychological and behavioural impacts of digital transformation necessitates knowledge of its distinct characteristics.

According to Bandura (2012), an employee's degree of self-efficacy determines their openness to embrace new technologies. Self-efficacy is the conviction that one can accomplish given goals by acting according to the necessary standards. Workers who feel they can use new technology are more likely to embrace these developments with optimism and determination.

Companies may use many strategies to increase employee confidence and excitement throughout the digital transition. One of the most important means of increasing employee confidence is providing comprehensive training courses supporting emotional resilience and technical understanding. This aligns with the Theory of Planned Behaviour, which emphasises how a person's perception of their ability to control their behaviour depends on their motivation (Ajzen, 2012).

This idea has become even more relevant considering the digital expansion in the food industry. Those workers who feel they possess the necessary knowledge and skills to use new technologies properly are more inclined to embrace these developments and fulfil their changing responsibilities. Businesses may use a mixed training and support approach to raise supposed behavioural control. This may include valuable seminars where employees could utilise recently acquired technology in a low-risk environment, building their confidence through direct experience.

Moreover, providing staff members with continuous technical support and fostering a culture that invites questions, and learning would help them to feel more in charge of their ability to change with the advancement of technologies. Ajzen's (2012) theory further underlines the importance of eliminating any impediment to alter conduct. From the digital transformation perspective, this includes identifying and mitigating common challenges employees face when implementing new technology.

Encouragement of a development mentality is another crucial component of enhancing workers' apparent behavioural control. Emphasising that hard work and commitment can develop technological skills rather than relying solely on natural talent can help businesses motivate employees to view challenges as opportunities for growth. Inspired by the Theory of Planned

Behaviour (Ajzen, 2012), this perspective of view might result in more drive and readiness to interact with new technology.

Companies might also use social influence, another essential component of the Theory of Planned Behaviour (Ajzen, 2012). Emphasising the success stories of staff members who have embraced new technologies can help companies establish suitable subjective criteria for digital transformation. Other staff members might be driven to match them as they can also effectively negotiate these adjustments.

Programmes for employee representatives and cultural committees support worker engagement and feedback sharing (Neill et al., 2020). Such initiatives create an open and active communication environment, therefore boosting staff confidence and the acceptance of initiatives involving digital transformation.

It is important to note that people's responses to these digital transformation events mostly rely on their choices. AET claims that human qualities might affect how employees see and respond to technical developments in the food industry (Weiss & Beal, 2005). For instance, although some people with more conventional preferences might have more negative emotions, individuals more open to new experiences could find the digital transformation more intriguing and appealing.

Dealing with the psychological and behavioural consequences of managing technological transition mainly relies on the leadership communication style. Effective communication techniques answer employee worries about change, including failure, personal loss, and inadequate support. Studies reveal that whereas monologic communication might lead to more resistance, dialogic communication relates to less resistance to change (Simoes & Esposito, 2014).

Dealing with the psychological and behavioural effects of digital transformation calls for a whole strategy, including personal qualities, effective communication methods, and leadership development. By addressing these elements, companies may reduce stress and anxiety related to technological transition, boost the adoption of new technologies, and inspire workers' confidence and motivation all along the digital transformation path. This knowledge may guide policies for customer involvement, change management, and staff development, helping create a more effective and emotionally uplifting digital transition in the food industry.

1.13.3 Group Dynamics

The interplay of group dynamics and technology acceptance is crucial in digital transformation, especially within the framework of Industry 4.0 and integrating new technologies in professional environments. The impact of collective behaviour on technology adoption is an essential aspect that organisations must consider when executing digital transformation strategies.

The dynamics within a group are crucial for accepting and implementing new technology inside a company. Attitudes regarding newly developing technology are formed in significant part by societal influence. Companies must provide cooperative settings where teams may share knowledge about these technologies and experiences, fostering group acceptance (Chaiken & Ledgerwood, 2012). Moreover, encouraging an awareness of innovation and teaching management about innovative approaches may greatly influence group attitudes towards implementing technologies (Petrillo et al., 2018). This awareness-raising campaign helps to create a positive group dynamic and encourages the adoption of new technology and procedures.

Fostering an organisational culture that encourages innovation is essential to group dynamics and technology acceptance. The influence of social identity on behaviour within groups suggests that organisations ought to foster an identity that emphasises innovation and adaptability (Ellemers & Haslam, 2012). Organisations that want to involve their staff and use dynamic capabilities properly must create urgency about digital projects. Establishing a clear vision to guide transformation and turning it into concrete goals can help to build this culture (Ancarani & Di Mauro, 2018).

Addressing the various subcultures within an organisation is essential to understanding group dynamics and fostering technological acceptance. Understanding the social cognition influencing group behaviours can help leaders manage potential conflicts among different subcultures regarding technology acceptance (Fiske & Taylor, 2017). Using ideas from social cognition theory, leaders may create plans to overcome opposition, encourage acceptance, and advance a unified corporate culture in the face of technological change.

Social cognition theory holds that people in groups create collective perceptions and shared mental models that shape their attitudes and actions (Fiske & Taylor, 2017). These common values in the framework of the acceptance of technology might result in subcultures with different points of view on AI, automation and digitalisation. Based on their own experiences, knowledge, and perceived influence on their jobs, different departments or teams within an organisation may grow to see new technology differently (Fiske & Taylor, 2017).

Leaders may use numerous techniques anchored in social cognition ideas to solve possible disputes and encourage technological adoption among subcultures. Encouraging intergroup contact might help eliminate assumptions and misinterpretations about technology adoption (Fiske & Taylor, 2017). Group seminars and training courses, work rotation programs to expose staff members to multiple points of view, and cross-functional teams for technology implementation projects all assist in achieving this (Fiske & Taylor, 2017).

Leaders may shape group impressions by subtly crafting the story surrounding technology adoption. This entails stressing common objectives and advantages among different subcultures, paying attention to particular issues of every group, and adopting language that speaks to many subcultures (Fiske & Taylor, 2017). Leaders who do this help promote a more coherent grasp of the benefits and challenges related to technological transition.

Using social influence within groups could assist in increasing the adoption of technologies. Among the strategies include finding and involving influential individuals of every subculture as technology champions, highlighting early adopters' success stories and positive experiences, and generating chances for peer-to-peer education and assistance (Fiske & Taylor, 2017). This strategy utilizes social proof, a psychological and social phenomenon in which individuals observe and imitate the actions of others to guide their behaviour in a specific situation. According to Fiske and Taylor (2017), this approach can effectively shape attitudes and behaviours within groups.

Including members of many subcultures in adopting technologies could help lower opposition and boost buy-in (Fiske & Taylor, 2017). One may do this by setting up cross-functional steering groups, scheduling frequent feedback meetings and polls, and including ideas and issues into action plans (Fiske & Taylor, 2017). Giving staff members a voice helps executives instil responsibility and loyalty to continuous technological innovations.

Understanding the social cognitive mechanisms influencing group behaviours helps executives to properly handle problems and encourage technology adoption among several subcultures within their company. In the face of continuous technological change, this strategy promotes a more consistent and flexible organisational culture but also helps to encourage better adoption of technology (Fiske & Taylor, 2017). Leaders must understand that the human elements involved, especially the social and cognitive processes affecting how staff members see and interact with new technologies, often determine the effectiveness of technological applications (Fiske & Taylor, 2017).

Leaders should also understand that technology adoption is a journey rather than a one-time occurrence. As new technologies constantly grow, companies must encourage an attitude of continuous learning and adaptation. Along the way, this means regularly assessing the fit between technology and organisational subcultures, reacting to growing problems, and celebrating successes.

Lastly, using concepts from social cognition theory, leaders can traverse the difficult terrain of technological acceptance across multiple organisational subcultures. This strategy helps them establish a more harmonic and efficient workplace where technology is perceived as an enabler rather than a threat, therefore supporting the long-term growth and competitiveness of the company in an environment that is becoming increasingly digital.

Group dynamics and technical acceptance are crucial in digital transformation. Organisations must concentrate on influencing group behaviour to support the adoption of technology, foster a creative culture, and appropriately manage the many subcultures within the organisation. By focusing on these elements, businesses may help enable a more seamless shift to new technologies and processes, therefore boosting the success of their initiatives in digital transformation.

1.14 Occupational Safety and Health in the Digital Era

Technological advancements are reshaping OSH practices, influencing how risks are managed and addressed in the workplace. The transition from traditional OSH practices to digitalised systems, influenced by Industry 4.0 technologies, represents a significant shift in managing and monitoring workplace safety.

This transformation is driven by the increasing integration of advanced technologies such as cyber-physical systems (CPS), cobots, smart safety technologies, Big Data, and the IoT. These technologies introduce new paradigms in production, significantly redefining the landscape of OSH by transforming risk management and worker safety.

Industry 4.0 enhances the efficiency of production processes, enabling faster and more accurate decision-making. This shift towards a more digitalised approach to production means that traditional work environments are becoming more automated, with workers increasingly interacting with smart machines. This transition impacts OSH by altering the nature of job tasks, often requiring workers to engage in more knowledge-intensive and creative activities rather than routine manual tasks.

1.14.1 Risk Perception

Risk perception in the context of OSH involves assessing potential risks and their severity in the workplace, which is essential for preparing employees to navigate the dynamic relationship between technology and safety (Cheng et al., 2024; Martins, 2024; Schuett, 2024). Lack of adaptation and investment in employee training in organisations leads to increased human error in automated systems, which has serious consequences for operational processes and the safety of the working environment (Martins, 2024).

Managing risk perception with appropriate human supervision and combining technological advances with worker training is important to create a safe, digitized, and automated environment. This is particularly important for high-risk AI systems, which require continuous risk management throughout their lifecycle, including identification, assessment, and mitigation of foreseeable risks (Schuett, 2024). Organisations must cultivate a complex digital security culture that involves managers and employees recognizing and addressing risks (Digmayer & Jakobs, 2019).

Workers may perceive risks when new digital technologies are introduced into their daily work routines. Knowledge and attitudes towards risks play a significant role in shaping workplace safety practices. Risk-aware procedures and practices need an in-depth understanding of potential hazards in production processes, including current technological developments and legislation. Employees must maintain up-to-date risk knowledge and participate in safety improvement discussions (Digmayer & Jakobs, 2019).

A significant paradigm shift is required in how organisations approach safety and risk management. Industry changes introduce new risks, requiring managers to adopt new safety measures and mindsets. This transformation can enhance employee performance in managing advanced technology-related challenges (De Jesus-Rivas et al., 2016; Digmayer & Jakobs, 2019). Moreover, workers' risk perception significantly influences how they adapt and respond to technological change. Workers who perceive automation as a greater risk are more likely to support measures to counter technological change to protect their jobs. This illustrates how risk perception influences acceptance and resistance to digitalised industry, confirming its importance in industrial sectors (Bicchi et al., 2023).

Addressing the risks associated with digitalisation requires organisations to develop protective strategies, such as training and developing workers' and organisations' skills and capabilities (PECB, 2022).

1.14.2 New Emergent Risks (NER) in the Digital Workplace

Emerging risks in the food industry, driven by digitalisation, automation, and AI-based technologies, represent a growing concern as industries adapt to new advancements. Emerging risks refer to hazards that are either new or rapidly increasing, often arising from complex interactions between human operators and advanced technologies, including physical and psychosocial factors (Arana-Landín et al., 2023; Brocal et al., 2024; Heinold, Funk, et al., 2023).

The integration of advanced technologies into industrial processes can lead to stress, discrimination, job insecurity, and work intensification, which are significant psychosocial risks in digitalised workplaces (Heinold, Funk, et al., 2023; Moore, 2019; Providence Nwachukwu Akpa, 2024). Stress and anxiety among workers can arise due to the necessary changes in their work routines and environment, particularly when they are not adequately informed or involved in implementing these technologies. These psychological risks may sometimes be hidden from employees and management, highlighting the importance of proactively adopting in the management system of the organisation's good practices and prevention strategies, such as communication and training programs to ease the transition for employees (Arana-Landín et al., 2023).

The introduction of smart technologies, such as smart wearable Equipment for workers' protection and ambient intelligence, increases the complexity and dynamism of work environments, necessitating new frameworks for dynamic OSH management (Lemos et al., 2022; Pishgar et al., 2021; Podgórski et al., 2017). The integration of wireless communication technologies and sensor networks, when properly integrated, can monitor and detect hazards in real time, providing ongoing protection in autonomous and intelligent industrial environments. However, to ensure the reliability and effectiveness of these systems, actions such as implementing common technological platforms that can monitor network performance and link sensors to remote control centres are needed, contributing to reducing occupational risks by facilitating the integration of general surveillance applications (Badri et al., 2018). At the same time, this monitoring and tracking of workers can lead to micro-management and be a source of stress and anxiety (Moore, 2019).

As industries continue to embrace digital transformation and AI-driven technologies, OSH managers and employees must remain vigilant about emerging risks.

As industries increasingly adopt digitalisation, and AI-based technologies, new occupational risks have emerged, including ergonomic and psychosocial risks, as well as those associated with the use of cobots (Lemos et al., 2022). While these technologies can support workers, they can also contribute to fear and resistance among employees.

1.14.3 Psychosocial Risks

The increasing complexity of technology in the production systems can lead to various psychosocial risks that can be overlooked but are significant for organisations. Currently, measures to prevent psychosocial risks are implemented 57% less frequently than measures to prevent physical risks (Lemos et al., 2022).

Automation and digitalisation reduce hard physical tasks of manual labour but require complex management skills, abstract thinking and rapid problem-solving for unexpected situations (Leso et al., 2018). The relationship between psychosocial and musculoskeletal risks is particularly notable in automated contexts, where key interrelated causes include low physical activity, static postures, intense cognitive load, reduced workplace privacy due to close technological monitoring, and increased decision-making challenges compound these effects (Brocal et al., 2024).

The introduction of new technologies in the workplace can lead to increased stress and anxiety among workers. This stress may arise from various factors, including fear of job loss due to automation, pressure to adapt to new technologies and acquire new skills, increased monitoring and performance expectations, and the blurring of work-life boundaries due to increased connectivity (Erol, 2024; European Agency for Safety and Health at Work & Future Impacts., 2023; Min et al., 2019; Moore, 2019; Tepe, 2021). Additional contributors to stress include work intensity, workforce ageing, greater task complexity, job concentration, time management issues, potentially fewer opportunities for human interaction and even group bullying can further contribute to increased workplace stress (European Agency for Safety and Health at Work, 2018; Tepe, 2021; International Labour Organization, 2018).

The relationship between cognitive load and automation is multifaceted. Workers may experience cognitive underload due to monotonous supervision tasks in highly automated systems, leading to boredom and reduced concentration. Conversely, the transformation of roles into primarily supervisory positions overseeing multiple processes can increase cognitive demands and mental stress levels (European Agency for Safety and Health at Work, 2018). Intensive high or low cognitive demand periods can increase error probability (Steijn et al., 2016).

While AI-based technology and advanced robotic systems can optimise mental workload through various mechanisms, such as filtering information or reducing worker input assessment, it raises concerns about job satisfaction and mental health. The long-term impact remains uncertain, with some jobs becoming less fulfilling while others become more engaging. Digitalisation tends to replace repetitive tasks, allowing workers to focus on roles that require interpersonal skills, creativity, and problem-solving. However, new sources of workplace stress may offset these potential benefits, including heightened surveillance and strict automated time management systems (European Agency for Safety and Health at Work & Future Impacts., 2023; Horton et al., 2018).

The social dynamics within the workplace are also affected by automation. Automated systems can streamline operations, but may reduce job variety, or task deprivation, leading to a loss of control over tasks and expertise. This can diminish overall job satisfaction as tasks become more scarce, monotonous and predictable, stripping the work of cognitive challenges required to maintain the engagement (European Agency for Safety and Health at Work, 2018; Leso et al., 2018). Additionally, the heightened pressure to maintain productivity and adapt quickly can increase the risk of mental health issues such as stress and anxiety (Lemos et al., 2022; Min et al., 2019). Without adequate comprehension of these technologies, employees may feel disconnected, less capable in their roles and uncertain about responding to systems failures (European Agency for Safety and Health at Work, 2018). The constant need to update skills and knowledge to keep pace with new technological advancements can lead to pressure and stress on workers, potentially exacerbating feelings of job insecurity, a sense of being controlled, or a perceived loss of control over one's professional future (Arana-Landín et al., 2023; Lemos et al., 2022; Leso et al., 2018; Min et al., 2019).

Whilst these technologies often reduce person-to-person contact, in some cases, automated systems can provide workers with greater control over their time, potentially increasing opportunities for social interaction and teamwork, as workers are able to help colleagues more frequently (European Agency for Safety and Health at Work & Future Impacts., 2023). Nevertheless, it raises concerns about increased lone working and the dehumanisation of tasks. These can reduce job satisfaction and heighten feelings of isolation as the social aspects of work diminish and tasks become less varied. A dispersed workforce can be exposed to the risks resulting from the loss of peer support and lone working, which can impact OSH (European Agency for Safety and Health at Work, 2018). Additionally, by heightening work-related stress and potentially causing long-term health issues, automation may also contribute to more conflicts between employees and supervisors and among staff (Adem et al., 2020).

AI-based technology and robotic systems introduce constant monitoring of workers, increasing performance pressure that, in turn, can harm mental health (European Agency for Safety and Health at Work, 2019). The ability to continuously track employee behaviour, productivity, and performance can lead to privacy invasion, stress, and anxiety, particularly when workers are uncertain about what data is collected and how it is used (Adem et al., 2020; European Agency for Safety and Health at Work, 2018; Lemos et al., 2022) for decisions regarding job restructuring, role changes or workforce replacement. This stress can be exacerbated by a lack of transparency while monitoring workers' performance (Erol, 2024; Moore, 2019). Adaptive automation systems may alleviate some pressure by adjusting task speed to prevent overload while allowing workers to retain control over their workload, which could support greater acceptance of robotic systems (European Agency for Safety and Health at Work, 2018).

The flexibility and mobility of digital and automated technologies enable work to occur anywhere and anytime, further blurring the line between personal and professional life, which can become a significant psychological risk (Erol, 2024; Leso et al., 2018; Tepe, 2021). Although production workers may not typically experience this stress, adopting digital and automated workplaces is a common consequence, as it can unbalance the work-life ratio. Employees often feel pressured to respond to messages and resolve issues outside regular hours, intruding on their rest and leisure time (Lemos et al., 2022). Additionally, the constant availability of information systems on personal devices means that workers might receive machine status updates or notifications after hours, potentially leading to overwork and disrupting their work life (Moore, 2019). While some researchers suggest that flexible work schedules could improve work-life balance by allowing workers to manage their own pace, this benefit is not universal, as changes in job structure can make it harder for employees to maintain balanced demands throughout the day (European Agency for Safety and Health at Work & Future Impacts., 2023; Polak-Sopinska et al., 2020).

To mitigate these psychological risks, organisations should acknowledge the need for expertise to address the risks and provide adequate training and support to help workers adapt to new technologies. This includes offering training programmes on digital skills, establishing clear protocols, and fostering open dialogue with employees (Arana-Landín et al., 2023; Moore, 2019).

The growing complexity of new technological systems in the industry presents unique challenges through the intricate interactions between job demands, organisational factors and management aspects, which can lead to psychological hazards and require careful attention and management. Despite the importance of these risks, engineers and systems designers often overlook them while they are increasingly relevant for OSH management systems (Adem et al., 2020; Badri et al., 2018).

1.14.4 Physical, Chemical and Biological Risks

The introduction of new technologies often results in an overall improvement in worker well-being, driven by enhanced ergonomic design, injury prevention, reduced physical risks, and reduction of monotony in tasks (European Agency for Safety and Health at Work & Future Impacts., 2023; Heinold, Rosen, et al., 2023; Kadir & Broberg, 2020). In Europe, musculoskeletal injuries represent around a quarter of sick leave days, causing a representative production loss (Polak-Sopinska et al., 2020). Advanced robotic systems and automation technologies present opportunities to optimise workplace conditions, particularly regarding physical workload reduction and improved physical health (Heinold, et al., 2023).

The greatest impact of these technologies occurs when they replace existing work methods with more ergonomic routines, which is often a primary goal of adopting automation (Heinold, et al., 2023). Collaborative robots, for instance, can assist workers with strenuous tasks, allowing older workers to continue performing jobs involving physical effort and creating better access to work for disabled people (European Agency for Safety and Health at Work, 2018).

However, the implementation of automation and robotics is not without challenges. While automation can reduce repetitive tasks, collaborative robots may increase strain and lead to musculoskeletal injuries if tasks requiring worker assistance are highly repetitive, robot-driven in speed, and lack task variety, simultaneously reducing the availability of roles and leaving workers with specific or specialised tasks (European Agency for Safety and Health at Work, 2018; Lloyd & Payne, 2023; Steijn et al., 2016). To address this, industry managers should ensure that robots adapt to human working speeds rather than forcing workers to adapt to robot-paced operations.

Robotic systems and AI-based technology can significantly reduce the need for workers to perform hazardous tasks or work in dangerous environments. This includes reducing exposure to confined spaces, work at height, noise, equipment vibration, and contact with moving machinery (Ayed & Hanana, 2021; European Agency for Safety and Health at Work, 2018). In the food industry, automation reduces manual handling of heavy loads, exposure to extreme temperatures, repetitive movements, and standstill positions.

However, increased digitalisation can lead to more sedentary work, which is associated with health risks such as obesity, cardiovascular disease, type 2 diabetes, mental disorders, and certain cancers (European Agency for Safety and Health at Work, 2018, 2019; Horton et al., 2018; Lemos et al., 2022). Wearables can help mitigate these risks by warning workers about their behaviour and prevent it by encouraging pauses, movement, or different postures.

Automated equipment can introduce mechanical, electrical, or thermal risks, and operators may still face physical hazards such as noise, lighting, environment temperature, work pressure, vibration, radiation and chemical exposure (Leso et al., 2018; Tepe, 2021). Collaborative robots pose specific risks, including collisions, trapping, or entanglement, particularly if safety systems fail. Preventive measures like isolation cannot be used, and it is necessary to adopt measures such as reduced speed and force near humans, soft, rounded edges, or vision systems. Sensors play an important role in ensuring safety; however, they can fail due to programming errors, malfunctions, dirt, electrical interference, or cyberattacks, potentially leading to workers' collisions (European Agency for Safety and Health at Work, 2018; Leso et al., 2018).

Eye health can also be affected due to increased screen time linked with digital technologies, potentially leading to eye injuries or visual fatigue (Adem et al., 2020; Tepe, 2021). However, digitalisation and automation bring the opportunity to decrease interaction with screens by optimising how information is presented or allowing other types of interactive systems, such as verbal communication. Presenting more selective and clearer information according to user needs reduces screen time (European Agency for Safety and Health at Work & Future Impacts., 2023). Often, reducing screen time has the parallel effect of reducing sitting time (Heinold, Rosen, et al., 2023). When automation decreases or removes physical activity, it can lead to a more sedentary lifestyle, increasing the risk of cardiovascular disease, obesity, diabetes or even anxiety or musculoskeletal injuries resulting from poor postures (European Agency for Safety and Health at Work, 2018).

Beyond physical and ergonomic risks, robots reduce chemical and biological hazards by removing workers from dangerous environments, enabling remote monitoring, and lowering the risk of accidents and contamination (Costantino et al., 2021; European Agency for Safety and Health at Work, 2018). However, robots can also expose workers to harmful particles, such as dust or gases, during cooperative tasks in shared environments (Adem et al., 2020; Tepe, 2021).

As can be perceived, technology impact, effectiveness, and safety in physical, chemical and biological risks will largely depend on how it is utilized. Therefore, when planning, careful consideration should be given to the characteristics of the equipment and technology to be selected and implemented, as well as the work environment and organisational factors to optimise outcomes and fully harness the potential of digitalisation, automation, and AI-based technologies.

1.14.5 Cybersecurity

The increasing digitalisation, connectivity, data exchange and online data processing in modern industries, including the food sector, have introduced risks inherent to the technology itself. Cyber-attacks threaten OSH and endanger workers (Polak-Sopinska et al., 2020).

As industries adopt new technologies, the interconnected nature of operations amplifies the potential impact of cyber-attacks, which can have far-reaching consequences, potentially compromising worker safety and the integrity of manufacturing processes (Tepe, 2021). The primary goal of cybersecurity in this context is to safeguard the confidentiality, integrity, and accessibility of information processed, stored, and transferred within industrial systems while ensuring system continuity and performance (Serap, T., 2021; Polak-Sopinska et al., 2020).

Integrating Information and Communication Technologies (ICT) into manufacturing equipment, such as machines and robots, has made cybersecurity a critical concern in industrial settings. Ensuring reliable systems are protected against unauthorized access, data breaches, and potential malfunctions caused by cyber-attacks is paramount (European Agency for Safety and Health at Work, 2018; Tupa et al., 2024). Failure to implement adequate cybersecurity measures can result in serious work accidents, especially when dealing with smart robot systems susceptible to hacking (Çelik & Fatih, 2017; Steijn et al., 2016).

Beyond traditional cybersecurity concerns, adopting AI-based technologies and advanced digital systems introduces additional complexities and risks. For example, AI systems can introduce issues related to data and algorithm biases, leading to biased decisions and discrimination (Steimers & Schneider, 2022; Vieweg, 2021). The integration of digital ultra-platforms and IoT increases system complexity, which can result in risks such as total network collapse, increased cybercrime, and new social and political power structures (Caporuscio et al., 2021; Eskindarov et al., 2019; Özdemir & Hekim, 2018). These factors affect the technical aspects of industrial operations and have significant implications for worker safety, privacy, and workplace equity.

Industrial cybersecurity faces specific vulnerabilities. For example, malware can infiltrate robotic systems via laptops or portable media like USB drives during reprogramming work. Moreover, industrial communication systems often rely on wireless technology, making them more susceptible to interference or malicious attacks, potentially disrupting communication between sensors and robots. The practice of remote maintenance by external suppliers also presents potential access points for hackers (Steijn et al., 2016). To mitigate these risks, industries implement various countermeasures, including anti-malware software, intrusion detection systems, and segregated network architectures (Polak-Sopinska et al., 2020; Steijn et al., 2016). However, the perceived level of risk varies depending on the specific industrial context. Most robotic systems, particularly those not connected to the internet or vital servers, are less likely to be targeted due to such attacks' high-risk, low-reward nature. Cyber-attacks design to harm a company are more likely to target larger digital infrastructures. Nonetheless, this does not negate the importance of implementing robust cybersecurity measures to protect production lines, workplaces and digital infrastructure (European Agency for Safety and Health at Work & Future Impacts., 2023).

In addition to system security, data privacy has emerged as a significant concern in OSH and cybersecurity. Both employers and employees are increasingly aware of the need to minimize data collection, inform workers about data-gathering practices, and adhere to current data privacy protection laws (European Agency for Safety and Health at Work & Future Impacts., 2023). Furthermore, the stress induced by the fear of data theft or the introduction of false information into systems can negatively affect workers' mental health (Arana-Landín et al., 2023).

As industries continue to embrace digital transformation, the intersection of cybersecurity and OSH becomes increasingly relevant. Ensuring robust cybersecurity measures is not just about protecting data and systems but also about safeguarding the health and safety of workers in this evolving industrial landscape (European Agency for Safety and Health at Work, 2018; Polak-Sopinska et al., 2020; Tepe, 2021).

1.14.6 OSH Training for Industry 4.0 Technologies

As new technologies are introduced, workers, particularly those in lower-skilled positions, require updated skill sets and adequate support to adapt (Leso et al., 2018; Moore, 2019). Traditional OSH training, which has typically focused on physical risks, now must address the mental and psychosocial risks associated with robotic systems and AI-based technology in the workplace. This includes preparing workers for the challenges of people analytics applications and other emerging technologies (Moore, 2019). Training should be provided before starting a job, after changes in workplace conditions or tasks, and when new technologies are adopted (Leso et al., 2018).

The rapidly evolving nature of technology in the workplace needs a shift towards lifelong learning and continuous professional development (Leso et al., 2018; Polak-Sopinska et al., 2020). Training pedagogy should be adjusted to accommodate this ongoing learning process, focusing on problem-solving, principles, and traditional skills. Workers should be empowered to understand and choose their learning pathways and styles (Moore, 2019).

Innovative approaches to OSH training are emerging, leveraging simulation technologies to overcome time, space, and equipment constraints. These methods have shown promise in increasing the permanence and quality of training (Tepe, 2021). Virtual reality, for instance, offers significant opportunities for effective training. It allows workers to experience potential job accidents in a virtual environment, enhancing training effectiveness by making it more immersive and engaging and preparing for real-world scenarios (Leso et al., 2018).

The relevance of workers' training is not only on how to use new technologies but also on how these technologies benefit them, such as avoiding strain injuries or providing more control over their time. Some organisations have found success in identifying workers with a special interest in technology and inviting them to participate in specialized training, creating “technology ambassadors” who play a vital role in raising awareness of the system’s benefits and serve as accessible points of contact for colleagues with questions or concerns (European Agency for Safety and Health at Work & Future Impacts., 2023).

Adopting training strategies to promote a human-centred approach in technologically advanced industries is undoubtedly necessary for preparing workers to handle emerging risks (Leso et al., 2018; Moore, 2019). An implementation plan should organise regular training and align OSH training with new technologies to ensure the content is relevant and the knowledge and skills gained are applicable and used (Moore, 2019).

Implementing on-the-spot training devices, such as head-mounted displays or tablet computers, presents opportunities and challenges. While these tools can provide immediate guidance and reduce the need for prior knowledge, they may also lead to work intensification and potential workforce deskilling, which can increase OSH risks. Care must be taken to balance the efficiency gains with the long-term skill development of workers (Moore, 2019).

In small businesses and startups, where experimentation with new technologies is common, there is a risk of neglecting to ensure that safety standards are met until it is too late. Effective communication and training are essential to ensure workers can quickly comprehend the complexity of new technologies and prepare for potential hazards, preventing new risks from emerging (Moore, 2019).

By focusing on continuous learning, innovative training methods, and worker engagement, industries can better prepare their workforce for the challenges and opportunities presented by technological advancements.

Implementing OSH in a Digital Context

The implementation of OSH in a digital, automated and AI-based technological context requires a comprehensive process to manage industrial systems from their inception through their operational lifecycle. Identifying and addressing risks early in the lifecycle, during the design phase of industrial projects, new technologies, equipment, processes, procedures, and well-planned workplaces are particularly advantageous. Incorporating risk assessment at this stage provides greater flexibility for risk management and reduces the financial implications of addressing hazards later in the project's lifecycle (Badri et al., 2018). A proactive approach to risk assessment, particularly during the early stages of designing innovative applications, coupled with suitable management strategies, ensures the protection of workers and effectively addresses emerging OSH concerns (Leso et al., 2018).

The foresight to ensure safety, efficiency, and continuous improvement at every stage - optimizing safety, preventing system failures and mitigate their potential impact on worker safety and organizational operations - is the core of a resilient and worker-focused digital transformation.

Annex II contains non-exhaustive guidelines to provide a framework for safe and compliant operation of robotic systems and AI-based technology, encompassing the design, implementation, and operational stages. For a comprehensive approach, relevant Regulations and Standards should be consulted and applied to ensure compliance and best practices implementation.

1.15 Design Considerations

The design phase of digitalization, automation, and AI-based technologies in industry, where food industry is included, is important for ensuring OSH. By considering safety aspects early in the development process, companies can mitigate risks and enhance the overall safety and efficiency of their operations. This approach not only aligns with regulatory requirements but also addresses the ergonomic, cognitive, and operational needs of workers who will interact with these technologies.

Experts emphasize that the most important control measures are implemented during this stage, as many risk factors can be mitigate if a technology is designed with safety in mind. Relevant regulatory requirements must be adhered to, and establishing design principles guided by standards is highly valuable and should be incorporated during the development of new technology. A fundamental requirement during the design phase is conducting a thorough risk analysis, as mandated by European Machinery Regulation 2023/1230/EU, based on the technology's intended application (Steijn et al, 2016; Polak-Sopinska. A., et al., 2020). This analysis should consider all possible scenarios, although it is important to acknowledge that despite best efforts during the design phase, unforeseen situations may still arise when robots are put into operation. These situations could stem from improper use, unexpected interactions between software systems, or scenarios that were not anticipated during the design process. Therefore, the design must include provisions for human intervention (Stacey, N., et al., 2018), such as easily accessible or remotely activated emergency stop functions (Steijn, W., et al., 2016) and clear guidelines on how and when humans should intervene.

The increasing adoption of automation and robotic systems in the workplace has led to concerns about the potential for work to become dull and monotonous, if humans are relegated to assisting robots with repetitive tasks. To prevent this issue, is important to clearly define the roles of both humans and machines in the workplace (Steijn, W., et al., 2016), as well as involving end-users during development. Their insights can help ensure that the technology is user-friendly, that safety measures are practical, and that the system is fully integrated into the existing work environment. This involvement also helps build acceptance of the technology among workers, which is crucial for its successful implementation.

Rather than designing work processes based solely on technical possibilities, a more effective approach would be to structure them from the perspective of employees who regularly will operate or maintain robots. This human-centric approach can help prevent underload and overload, contributing to a challenging and engaging work environment and enabling a significant reduction of many of associated risks (Stacey et al., 2018; Steijn, W., et al., 2016).

Costumer demand or competition can add pressure to accelerate new designs quickly, increasing the risk of design flaws, which may not be identified until after the equipment is in use (Stacey, N., et al., 2018). To mitigate this risk, organisations should take the time to thoroughly test new systems and consider their capability with existing production lines and work environments. This includes addressing potential challenges such as increased noise levels, added costs, or the need for significant changes to the work environment (Heinold, E., et al., 2023a). Other considerations during design involve using the best available technology and software, certified components, developing standardized symbols for instructions and sharing best practices across industries (Steijn. W., et al., 2016).

The design phase should also consider the need for robust safety measures, such as integration of wireless sensor networks and technical support systems that monitor and manage risks in real-time (Serap, T., 2021). These technologies, along with properly designed safety platforms, can help prevent accidents in autonomous and smart industrial environments by providing early warnings and enabling rapid responses to emerging hazards (Polak-Sopinska, A., et al., 2020).

The design of digitalized, automated, and AI-based technologies should be centred on the physical, mental, cognitive and social characteristics of humans. The formation of multidisciplinary teams that draws on the expertise of engineers, IT, psychologists, social and occupational scientists, ergonomists, medical professionals, designers, is important to create systems that effectively integrate human work and smart solutions (Polak-Sopinska, A., et al., 2020). Some authors underscore the pivotal role of ergonomics and human factors research in OSH within the context of emerging and advanced technologies. Ergonomists and engineers are fundamental in designing and operating new systems and processes to mitigate the adverse effects brought by industrial paradigm shifts (Badri et al., 2018). The design of a robot must incorporate ergonomic principles for users and maintenance personnel, designing with future maintenance in mind and virtually testing software (Steijn, W., et al., 2016).

An effective safety system incorporates a status check during the design, ensuring that all internal components are functioning correctly and that external safety measures are operational before work commences. To enhance system knowledge of potential risk and monitorization, it is advisable to program the system to report near-misses and accidents originating from it (Heinold et al., 2023a).

1.16 Implementation and Transition of a Digital System

The implementation of new technologies, such as robotics and AI-based systems, requires careful consideration of OSH aspects. Identifying the activities susceptible to automation, assessing existing risks, determine how automation can minimise them or introduce new ones and involving workers, management and specialists in the implementation process helps identify priority areas and decide whether these technologies should be implemented or not.

By integrating workers' inputs early in the implementation process, organisations gain valuable insights into their opinions and thoughts about the system, including OSH, which increases the likelihood of success (Heinold et al., 2023a). Concerns and resistances of the employees must be addressed by comprehensively and transparently informing them about goals, advantages and above all risks of the transformation (Digmayer, C., & Jakobs, E., 2019).

Once the decision to adopt a technology has been made, the next steps involve selecting appropriate technologies, performing risk assessments, obtaining cost proposals and planning the layout. When integrating a system into an existing production line, is typically conducted initial test setups and preliminary factory acceptance testing to validate the system. After testing, the system is installed on-site, followed by real-time functionality testing under real operating conditions (Heinold, E., et al., 2023a). New systems must also be tested to monitor emerging risks, determine safety measures, and make necessary adjustments to ensure optimal safety performance.

As in the design phase, a risk assessment should be conducted to identify all potential unsafe conditions and possible unsafe acts during all the steps implementation of the new work system involves. These risks should subsequently be eliminated or mitigated to ensure a smooth implementation or transition on a safe working environment. Encouraging safe behaviours and fostering a safety culture within the organization is always beneficial, and in this context, it is very advantageous. Employees who assemble, configure, position robots in the premises, maintain and operate the new system, as well as the supplier or any other stakeholders involved with the equipment, must possess strong safety knowledge (Steijn, W., et al., 2016). Suppliers, installers and system integrators are responsible for verifying that robotic systems are correctly positioned, and functioning properly (Steijn, W., et al., 2016).

During the transition from a conventional system to the adoption of new technologies there is potential for risks, especially if the new system needs to be integrated with the existing one and the infrastructure is not suitable for the new technologies being introduced. Another source of potential risks is the confusion that can arise when workers use both old and new systems simultaneously, potentially leading to misinterpretations about the technology's behaviour (Stacey, N. et al., 2018).

To address these challenges, future operators should participate in the testing phases and provide feedback, including their OSH concerns. Incorporating OSH considerations during implementation and integrating these systems into the OSH management framework at an early stage is critical not only for successful implementation but also for long-term operation. This proactive approach reduces the need for revisions later and minimises initial risks to workers (Heinold, E., et al., 2023a).

Providing additional instructions and standardized interfaces for programming and operating the equipment system is also a means of enhancing safety. Supplier/installer bear the responsibility of providing these instructions, while the end-user must ensure that their employees possess adequate knowledge to follow them correctly. Proper instruction, communication and information are fundamental components of safety, particularly as workplace environment evolve to incorporate fewer physical barriers (Steijn, W., et al., 2016).

It is not enough to simply provide instructions; workers must also be trained on how to safely operate the equipment. Training is an important control measure to prevent accidents and near-misses, ensuring that employees are knowledgeable about the systems they interact with (Steijn, W., et al., 2016) and should take place prior or during the actual implementation of the system. When additional information is needed, because of the impact the new system has on workers the training should be reinforced with a bigger number of sessions (Heinold et al., 2023a). Suppliers and employers share the responsibility for ensuring that users are adequately trained, contributing to maintain safety as technology advances (Steijn, W., et al., 2016).

Therefore, clear communication is required to maintaining workplace safety, especially when dealing with complex machinery and robotic systems. Open and effective communication among all parties involved, including the safety team, ensures that everyone understands the associated risks and responsibilities involved (Steijn, W., et al., 2016). Miscommunication, especially in scenarios with multiple procedures for different types of machines exist, can lead to unsafe acts and compromise overall safety. (Stacey, N. et al., 2018).

Constant change or innovation in the workplace can lead to mental health issues if workers' skills do not keep pace with technological advancements. A lack of skills can also prevent employees from performing a good work, potentially compromising OSH because of human error (Stacey, N., et al., 2018). Addressing these challenges through upskilling and reskilling fosters a safe and capable workplace, as discussed before in "Competence development".

1.17 Use and Operation

To ensure safety in environments where robots are used, implementing robust internal procedures, regulations and rules of conduct is important as a control measure. These measures may include encouraging a culture where employees feel comfortable pointing out unsafe behaviours, providing feedback on safety, conducting regular checks on the functionality of safety systems, and performing regular conformity assessments related to safety regulations (Steijn et al., 2016).

During operation, robotic systems must adhere to OSH principles to protect workers and others in the vicinity. Continuous risk assessment supports eliminating or mitigating hazards through effective preventive or control measures.

The outsourcing of robotic systems implementation can lead to scenarios where the operators have limited or no understanding of the specific instructions or functionality of the robot. This knowledge gap, or the robot's use in environments for which it was not designed, can potentially create hazardous situations, not because the robot is inherently unsafe but due to its inappropriate application (Steijn, W., et al., 2016).

Continuously providing comprehensive worker training is fundamental to sustain awareness of potential risks, transmit knowledge, and emphasise the importance of following robotic systems instructions and safety rules. Assessing the effectiveness of this training is necessary to ensure the knowledge has been effectively transmitted and absorbed.

Updated work instructions help ensure safe and effective operations in increasingly complex work environments. As the variety of physical assets and their associated properties expand, so does the need for detailed work instructions. These instructions are especially important in regions and sectors employing low-qualified workers who rely heavily on them to complete tasks safely and correctly (Gutsche, K. & Droll, C., 2020).

The implementation of augmented reality (AR) – based work instructions has been shown to have a significant positive impact, reducing the average time required to complete tasks. Workers using AR-based instructions also report finding them more helpful than their paper-based counterparts (Gutsche, K. & Droll, C., 2020).

Incidents often occur during activities outside of regular operation, such as maintenance procedures and subsequent testing (Stacey, N., et al., 2018). Maintenance tasks may present specific challenges, including limited accessibility to areas that are too high, narrow, or poorly lit, which can introduce additional hazards.

A thorough task-risk analysis before beginning any maintenance intervention is of paramount importance. Suppliers should provide training and develop detailed plans of action, while operators and maintenance technicians should diligently record hazardous situations and provide feedback to OSH teams and suppliers (Steijn, W., et al., 2016).

Implementing a lock-out/tag-out procedure ensures that employees have control over the system, preventing any inadvertent startups or exposure to charged electrical components. Additionally, mandatory permits should be established for carrying out maintenance activities (Steijn, W., et al., 2016).

Developing a schedule for preventive maintenance, addressing software irregularities promptly, and performing necessary equipment adjustments (Steijn, W., et al., 2016) are important strategies to reduce the likelihood and magnitude of failures.

A well-developed robotic system is user-friendly and includes built-in mechanism to periodically conduct systematic internal checks, ensuring that safety systems are functioning correctly, along with conformity assessments to meet safety requirements (Steijn, W., et al., 2016).

Regular inspections conducted by safety specialists, and technology experts, can identify potential new threats that may arise over time, such as those related to wear and tear (Heinold, E., et al., 2023a). Monitoring and recording difficulties, failures and errors can aid in identifying appropriate control measures and provide suppliers with valuable information to continuously improve their designs (Steijn, W., et al., 2016).

Good housekeeping practices and workplace organization that prioritize human needs are also key safety considerations (Steijn, W., et al., 2016).

The operation phase of robotics and AI-based technology in the industry requires a comprehensive and dynamic approach to safety. This approach involves the continuous improvement of practices, regular training, and active communication among all stakeholders to ensure that technological advancements do not compromise workplace safety (Steijn, W., et al., 2016; Heinold, E. et al., 2023a). By implementing these strategies, organisations can create a safer work environment that maximizes the benefits of robotic systems and AI-based technologies while minimizing potential risks.

1.18 Promoting Positive OSH

1.18.1 Safety Culture

There is ongoing debate regarding the precise definitions of safety culture and safety climate. In this handbook, safety culture encompasses the core values, beliefs, and assumptions that guide decision-making and behaviour related to safety within an organization (Casey, et al., 2017; Guldenmund, 2000; Filho, & Waterson., 2018). In the era of digitalization, automation and AI-based technology, the concept of safety culture has evolved to include digital transformation approaches and newly perceived risks associated with advanced technologies. It now encompasses a broader range of factors, including perceived safety, data protection, machine safety, and process reliability, reflecting the complex nature of socio-technical systems in modern industrial environments (Digmayer., & Jakobs, 2019).

Understanding and addressing safety in complex systems, particularly those incorporating AI and automation technologies, requires consideration on the interactions and interdependencies between human, organisational, and technological aspects (van Nunen et al., 2022). The socio-technical structure proposed by Valente, J.L. & Palma-Oliveira, J., (2013) can be understood through a three-segments interrelational model. The human segment includes competence (knowledge, skills and experience), values, attitudes, behaviour, engagement, recognition and risk perception. The organisational segment comprises risk assessment and control, leadership, management and supervision, work systems, and adopted preventive measures. The work environment segment consists of equipment, operational protocols and housekeeping. This model highlights the importance of addressing safety culture at multiple levels within an organization.

In the digital age, developing of a safety culture requires a participatory approach that encourages responsible self-organization, empowers employees to take the initiative and lead decision-making processes related to safety matters (Digmayer, C., & Jakobs, E., 2019) and involves all organisational levels in the development of a digital safety culture (van Nunen, K. L. L., et al., 2022).

It is important to note that safety culture is not uniform across an organisation. Different subcultures may exist within departments or functions, leading to variations in safety culture assessments (van Nunen et al., 2022). This heterogeneity highlights the need for tailored approaches to developing and evaluating safety culture.

To successfully implement a safety culture, organizations must consider several aspects, such as leadership commitment, high quality safety training, employee participation and effective communication. Leadership commitment is paramount. Management must prioritize safety issues and demonstrate genuine dedication to safety values through time and actions, (Digmayer, C., & Jakobs, E., 2019; Ala, Y., et al., 2020; Casey, T., et al., 2017) to build trust and promote a shared vision of safety.

High quality safety training plays a significant role in improving both safety culture and climate (Ala, Y., et al., 2020; Casey, T., et al., 2017) by raising awareness of workplace hazards and promoting safe behaviours. In the context of digitalization and AI-based technologies, training should also include specific modules on safety considerations related to new systems and processes (Ala, Y., et al., 2020).

Organisations should adopt approaches that involve employees in decision-making processes and address their perceived risks seriously. This participative approach fosters a sense of ownership and allows workers to provide unique insights into potential safety concerns related to AI and automation systems (Digmayer, C., & Jakobs, E., 2019).

Open and transparent communication channels are essential for disseminating safety information, promoting collaboration, and addressing safety concerns. Employees should be aware of the reasons for safety culture measurement, the importance of their participation, and the objectives of the obtained results (Digmayer, C., & Jakobs, E., 2019; van Nunen, K. L. L., et al., 2022).

Establishing a positive safety culture requires a multi-faceted approach involving development, establishment, and maintenance. These three phases i) define the purpose and goals of safety culture initiatives, ii) development of a strategy, roadmap and plan that outlines the resources and processes necessary for implementation iii) the strategy must then be integrated into the organization's daily operations, with ongoing improvements made over time to ensure continuous progress (Digmayer, C., & Jakobs, E., 2019). Safety culture thrives through continuous monitoring and assessment of organizational strengths and areas for improvement, helping to refine safety practices results and make necessary adjustments (Digmayer, C., & Jakobs, E., 2019; van Nunen, K. L. L., et al., 2022).

To effectively shape and improve safety culture, it requires understanding which affecting factors are more influential in achieving positive outcomes. Identifying and addressing changeable and controllable key factors can lead to more effective resource allocation, solving potential environmental problems and decrease the rate of job-related accidents, generating a stronger safety culture overall (Thaden, T. & Gibbons, A., 2008; Ala, Y., et al., 2020; van Nunen, K. L. L., et al., 2022).

Organizations should proactively identify strengths and areas for improvement in their safety practices, however, an adequate interval between assessments is necessary to allow improvements to take place and yield significantly better results (Digmayer, C., & Jakobs, E., 2019; van Nunen, K. L. L., et al., 2022). A forward-thinking approach to hazard identification, risk mitigation, and the use of feedback mechanisms, combined with a mindset of continuous improvement, allows for targeted improvements and adaptations as technology evolves (Digmayer, C., & Jakobs, E., 2019).

Encouraging workers to engage with one another regarding unsafe practices and undesirable behaviour related to robot interactions, sharing best practices among themselves and ensuring the organization provides feedback to employees when safety rules are breached (Steijn et al., 2016) contributes to a safe work environment and promotes a strong safety culture.

1.18.2 Safety Climate

Though safety climate is often discussed in conjunction with safety culture, they differ in scope. Safety culture represents a broader organisational commitment to safety, encompassing long-term risk management strategies, safety management systems, and organisational assessments (Li, J., et al., 2022). In contrast, safety climate is narrower and more measurement-focused, often assessed through surveys and other tools to gauge employees' perceptions of how safety is prioritised and managed at various organisational levels (Casey, T., et al., 2017).

Safety climate acts as a snapshot of safety culture, providing a sectional view of how safety practices are perceived at any given time within the workplace and refers to the collective perceptions, beliefs, and attitudes of workers regarding safety within their organisation at a specific point in time. It is influenced by environmental and situational factors, making it a temporary and dynamic phenomenon, subject to changes on ongoing organisational practices and technological shifts (Ala, Y., et al., 2020; Filho, A. & Waterson, P., 2018).

Automation and AI-driven systems are increasingly integrated into daily operations and require continuous assessment and adaptation, particularly as digital systems introduce new variables into traditional safety management frameworks and require a strong safety climate to ensure the workforce adapts effectively and safely to the changes, helping workers to feel confident that safety remains a priority, and this shared perception influences safety-related behaviours (Casey, T., et al., 2017). By fostering a safety climate where employees feel engaged, informed and valued, organisations can better manage the inherent risks associated with digital transformation (Ala, Y., et al., 2020; Casey, T., et al., 2017).

Particularly where interactions between humans and automated machinery exist, safety climate serves as a control mechanism, helping to identify, monitor, and mitigate potential risks and disturbances that may destabilize the system (Casey, T., et al., 2017).

1.18.3 Behaviour-Based Safety

Behaviour based safety encompasses any workplace behaviour that influences the potential for physical harm to people, property, or the environment. The two key aspects of safe work behaviour are safety compliance and safety participation. Safety compliance refers to adherence to mandate safety requirements, typically specified as rules and procedures. Safety participation, on the other hand, involves behaviours that contribute to developing a supportive safety environment, such as helping coworkers and demonstrating initiative (Casey et al., 2017).

The introduction of robots working near humans has necessitated the development of new safety techniques, including the use of sensors, vision systems, and design modifications to minimize risks. Understanding how workers will behave in these new environments is pivotal to ensure safety and mitigating risks (Stacey et al., 2018).

Many workers have reported a fear of physical injury from new systems, but this apprehension tends to decrease as they become more experienced and confident with technology and realize it is safe to use (Heinold, E., et al., 2023a). However, persistent negative attitudes towards the technology, often rooted in fears of job loss or lack of trust, can negatively impact job satisfaction, well-being, and ultimately, safety compliance. Addressing the root cause of these attitudes with a positive attitude and motivation towards technological implementation, is essential for successful technology implementation. To address OSH technological implementation challenges, organisations should adopt a holistic approach, considering various aspects of a situation to intervene in a targeted and efficient manner (Heinold, E., et al., 2023a).

In the food industry specifically, researchers have discovered that food handlers' knowledge of safe food handling practices does not necessarily translate into positive attitudes and behaviours. While food safety is traditionally viewed as a microbiological issue, it is now recognized as a behavioural issue as well. Safety culture and organisational factors, such as management support, training, communication, and employee involvement, play relevant roles in shaping food handlers' commitment and compliance with safety standards, thereby reducing the risk of foodborne illnesses (Taha, S., et al., 2020). The introduction of new technologies, such as AGILEHAND, can help address some of these issues by reducing the need for human contact with food products, thereby minimizing microbiological contamination risks.

To promote positive safety behaviours in digitalized environments, organisations must consider a range of behaviours, including adaptivity, proactivity and teamwork. This is particularly relevant in interdependent systems and in systems where risks are unpredictable. Shaping behaviours requires creating opportunities, motivation, and competence rooted in knowledge, skills, and expertise. While traditional safety climate literature has focused on explicit knowledge of rules and procedures, tacit knowledge and skills gained through experience are equally important (Casey et al, 2017).

The acceptance of advanced robotics and AI-based systems in the workplace can also be influenced by age and experience of workers. Older workers may find it more challenging to learn and adapt to new technologies and may experience higher levels of stress. Targeted interventions that motivate and support these workers in using new technologies can help them maintain their jobs longer and reduce stress levels (Heinold, E., et al., 2023a).

Monitoring worker well-being through technologies that track physiological variables, and environmental risks can provide real-time alerts and enable the adoption of preventive measures to mitigate hazardous behaviours, restore safety protocols, and avert injuries (Polak-Sopinska. A., et al., 2020). However, over-reliance on automated safety systems can also lead to a reduction in workers' practical knowledge of the processes, resulting in increased accident risks (Brocal, F., et al., 2019).

Accidents involving robots often occur due to the failures in observing safety zones or instructions, which can be worsened by inefficient procedures or malfunctioning safety functions.

Experts emphasize that users may became irritated and more likely to bypass safety measures or even modify the robot if procedures appear illogical or if safety functions frequently give false alarms, particularly in small companies (Steijn, W., et al., 2016). It is important to consider both extrinsic and intrinsic safety motivation. While extrinsic motivation is primarily driven by rules and procedures, intrinsic motivation is particularly important for encouraging discretionary behaviours such as participation, adaptivity, and proactivity. Engagement in safety behaviours is further strengthened by participation, communication and shared information (Casey et al., 2017).

Despite the challenges, instances of worker resistance or low acceptance of these systems have not typically resulted in the failure of the implementation (Heinold, E., et al., 2023a). Behaviour-based safety in the context of these technologies is influenced by several factors, including worker attitudes and commitment, trust in the system and the adequacy of training and preventive measures.

1.18.4 Risk Management in a Technological Context

Risk management in this context involves a systematic process of identifying, evaluating and controlling potential hazards associated with technological implementations (Tupa et al, 2017). As the food industry embraces digital transformation, it must consider a wide range of risks, including those related to cybersecurity, data privacy, operational disruptions, and worker safety.

The evolution of industrial settings towards increased digitalisation has introduced new dimensions to risk management. Real-time risk management has become particularly relevant in dynamic industrial environments, using data from networked devices and internet accessible systems. However, this technological integration raises significant cybersecurity concerns that must be carefully addressed (Badri et al., 2018).

An aspect of effective risk management lies in the adoption of an integrated approach that aligns with corporate policy, which must account for stakeholders' requirements and regulatory compliance whilst establishing appropriate risk objectives and strategies. Successful risk management must be deeply embedded within the organisational culture to ensure its sustained effectiveness (Tupa et al., 2017).

In the context of worker safety, early OSH management during technology implementation combined with worker involvement, human-centred design, and clear communication channels, are essential elements to address potential implementation issues (Heinold et al., 2023a).

Current OSH management systems, designed for conventional business ecosystems, may be insufficient to address the new hazards and health issues that arise with digital transformations. These transformations demand updated risk assessment methodologies, adaptive occupational health models, and innovative implementation methods that the existing OSH management system are not equipped to fully support (Merve, 2019).

Robotic systems and AI-based technology need to consider new types of risk assessments and specific sources of risk which are not typically addressed in traditional software safety standards and include extensive and complex state spaces of AI applications, AI-specific biases, technical peculiarities of AI systems, new types of failure modes and uncertainty in decision-making processes, enabling the selection of appropriate risk reduction measures (Steimers, A. & Schneider, M., 2022; Horton, et al., 2018). Moreover, traditional risk assessment methodologies are increasingly viewed as inadequate for evaluating emergent risks associated with advanced technologies. These tools often lack the flexibility to account for the complexity and evolving capabilities of modern systems, making them insufficient for accurately assessing risks in rapidly changing technological environments (Arana-Landín, G., et al., 2023; Heinold et al., 2023a).

Risk assessment is a tool that can be used within the risk management to hazard identification and risk analysis The risk identification process involves pinpointing the causes and sources of risk, i.e. the hazards that can lead to physical damage, Proper identification of OSH risks requires clearly distinguishing between hazard and risk (Fernández, F. B., & Pérez, M. Á. S., 2015). The concept of risk is not always consensual and for that reason this handbook adopted the definitions provided by ISO 45001:2018 and EU-OSHA. A hazard can potentially cause harm, affecting workers health and wellbeing, while a risk is the likelihood that harm will occur.

Risk identification aims to compile a throughout list of risks. With the introduction of new technologies new categories of risk must be considered due to the increased vulnerability and threats arising from the convergence of cyber-space, sophisticated manufacturing technologies, and the outsourcing of services. In the end we obtain a categorising risk into technical, process and planning sections, and ensuring that these are continuously evaluated to support optimal corporate performance (Tupa, J., et al., 2017).

A key aspect of risk analysis in automated and digitalised environments, such as those using robotic systems, is identifying hazards that may arise from direct and indirect sources. To understand why incidents, occur and why preventive measures fail, analyses must address both direct causes related to barriers and fundamental causes, such as organisational factors. This is especially challenging in the complex, interconnected environments typical of modern industry, where identifying a single causality is often impractical (Brocal, F., et al., 2019). Indirect causes include examining tasks performed by operators and other staff who might be exposed to the system's risks without having direct interaction with it. To effectively identify these risks, system integrators must document each task and consult users to anticipate all foreseeable hazardous situations, including those that might affect workers indirectly, due to interference with the system (Chiabert et al., 2018). Risk management in digitised industry benefits from a dynamic framework, sensitive to human and organisational performance (Brocal, F., et al., 2019).

Continuous and early-stage risk analysis, supported by advanced digital tools can help mitigate risks such as mental health issues and conditions related to sedentary work, making workplaces both safer and more responsive to emerging health challenges in the era of digital transformation (Lemos et al, 2022).

1.19 Measuring and Improving OSH Performance

To measure and improve OSH performance a systematic collection and analysis of data is involved to evaluate the effectiveness of OSH and identify areas for improvement. This process contributes to OSH performance and supports organisations to ensure the health and safety of their employees, comply with regulations, and operation optimisation.

Assessing safety culture maturity in an industry requires a combination of qualitative and quantitative information to capture the complex and multifaceted nature of safety culture.

Quantitative data provide objective, numerical data offering a measurable assessment of safety culture and its outcomes. It is common to use incident and accident statistics, safety performance indicators (SPI), and statistical process control (Pei, J., et al., 2023).

Qualitative information focus on subjective aspects of safety culture, exploring beliefs, values and attitude within an organisation. They may include interviews, focus groups, ethnographic studies, and document analysis.

Semi-quantitative method combines qualitative insights with quantitative metrics, for a structured yet flexible assessment of safety culture. Questionnaires with Likert scales and calculations to evaluate maturity models can be applied (Siuta, D., et al., 2022) to determine the safety culture stage.

1.19.1 Maturity Models of Safety Culture

Maturity models derived from the concept of safety culture and are used as an evaluation method to facilitate the systemic identification and improved management of a safety system within all areas of an organisation (Iftadi, I., et al., 2023). Various models have been developed and applied across different industries to assess safety culture maturity.

A typical maturity model categorizes safety culture into several stages or levels, providing a structured framework for assessment and improvement through a multi-dimensional set of criteria (Pei, J., et al., 2023; Iftadi, I., et al., 2023; Filho, A. & Waterson, P., 2018). The number of levels or stages varies depending on the chosen model, with each stage characterised by distinct attributes and representing a progression from the previous one towards an optimal state (Iftadi, I., et al., 2023; Filho, A. & Waterson, P., 2018). That said, the models' straightforward, linear approach to safety culture improvement may be overly simplistic. Workers' values and beliefs about safety may fluctuate, showing periods of growth and regression within relatively short time frames (Filho, A. & Waterson, P., 2018).

The assessment process inherent in these models benefits from and encourages active participation and engagement across all organisational levels, contributing to create a sense of ownership and responsibility for safety and fostering a culture of continuous improvement. Common outcomes of safety culture maturity models in organisations include regular assessments and the implementation of changes to enhance safety practices and behaviours.

Below is a summarized description of some of the most well-known and widely applied models, considering both scientific studies and organisational practice.

Westrum´s Typology of Organisational Cultures (Ron Westrum) – categorizes organisational cultures into three types: Pathological (focus on personal power, needs and glory), Bureaucratic (focus on rules and positions) and Generative (focus on the mission of the organisation). Emphasizes the importance of information flow within an organisation and its impacts on safety culture. Westrum Typology of Organisations was one of the first tools to assess safety culture (Filho, A. & Waterson, P., 2018).

Hudson Ladder Model or The Safety Culture Ladder (Patrick Hudson) – emphasizes the evolutionary nature of safety culture development and integrate both tangible and intangible aspects, translated in systems, practices, beliefs and attitudes. Is a hierarchical model, based on Westrum model that provides two new stages and a more detailed ladder of safety culture maturity, emphasizing the progression in five levels: pathological, reactive, calculative (replacing Bureaucratic), proactive and generative and is widely applicable in oil, gas, construction and healthcare (Filho, A. & Waterson, P., 2018) for being very adaptable to high-risk environments.

Safety Culture Maturity Model (Mark Fleming) – The goal of this model is to improve safety culture through the development of a systematic approach. Unlike other models that primarily emphasize the frequency of safety activities, it prioritises the quality of these activities and advocates for continuous improvement and ongoing assessment rather than intermittent evaluations. Proposes a Safety Management Systems involving six steps: safety culture vision, responsibilities, plans and actions, assessment, review and refine. It is designed to provide a continuous indication of safety culture change through 20 metrics, delineated to capture markers present in daily operations. Breaks safety culture into five levels, ranging from poor to excellent: Pathological, Reactive, Bureaucratic, Proactive and Generative (Flemming, M., 2013). Each level reflects a distinct stage in an organisation's journey toward fostering a mature and robust safety culture.

Swiss Cheese Model (James Reason) – A conceptual framework for understanding accidents and errors in high-risk industries, presenting multiple layers of defence (represented by slices of cheese) with potential weaknesses (holes) that can align and allow an accident to occur (Shabani, T. et al., 2024). The model emphasizes identifying and addressing "holes" in these defences, focusing on how different layers of defence (e.g. procedures, training, supervision) interact to prevent safety incidents.

The model gives importance to both active failures (errors by individuals) and latent conditions, which are systemic weaknesses, including inherent design flaws, equipment malfunctions and organisational factors like the organisational culture, leadership support and open communication channels (Shabani, T. et al., 2024).

This model helps to identify potential risks, understand the underlying causes of risks and to introduce preventive measures by visualizing how errors or failures can occur within complex systems. The core concept of multiple layers of defences makes it valuable in managing risks by integrating human and organisational factors. It has proven especially effective in industries with complex processes such as aviation, healthcare, nuclear power and transportation (Shabani, T. et al., 2024).

The Dupont Bradley Curve – this model emphasizes the importance of moving from a culture where safety is enforced by management to one where safety is a shared responsibility among all employees. In this model safety culture evolves through four stages: Reactive, Dependent, Independent, and Interdependent. Focus on the behavioural aspects of safety culture and the progression towards a more collaborative and proactive approach. Provides a clear and structured framework for organisations to assess and improve their safety culture. Each stage reflects the progression of individual responsibility and commitment to safety. Organisational factors such as leadership and management play a crucial role in the Bradley Curve model, as effective leadership is essential for fostering a positive safety culture and guiding the organisation through the different stages of the model. Communication and information flow between workers and management is relevant for identifying and addressing safety issues. (Siuta, D., et al., 2022). Figure 1 is a graphical representation of the stage's progression, where the curve illustrates the journey through four stages of safety culture maturity.

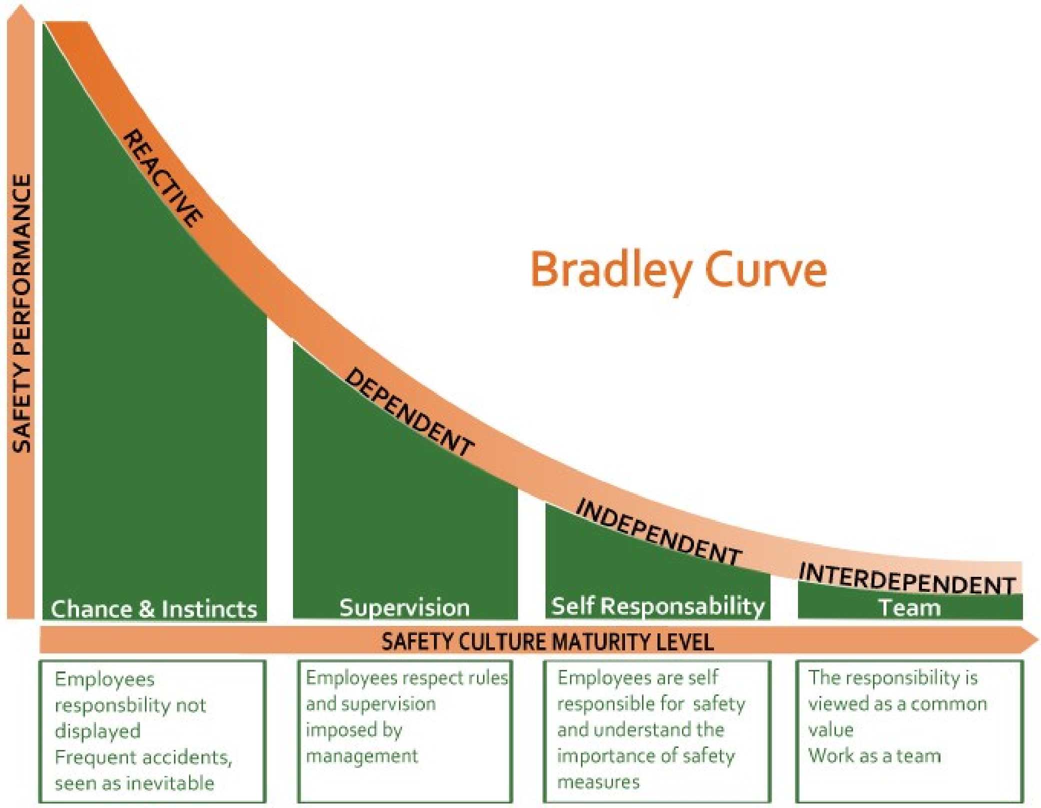

Figure 1. Graphical Representation of the Progression of the Bradley Curve Stages

Although it is beyond the primary scope of this handbook it must be referred the importance of food safety culture models in the food industry. Public awareness regarding food safety has been rising, along with an increasing number of certifications required by external organisations and legislation demanding organisations to implement and continuously improve their Food Safety Culture (Spagnoli, P., et al., 2024).

Organisations can evaluate their maturity through various methods, such as self-assessment surveys distributed to employees across different levels, functions, and roles, measuring specific food safety behaviours and attitudes. Similar to OSH maturity models, food safety maturity models are design to categorise organisations into different levels and promote continuous monitoring and improvement of food safety culture (Jaspersen, L., et al., 2016). The Food Safety Culture Maturity Model, by Wright was the first framework of its kind (Filho, A. & Waterson, P., 2018) and it has inspired numerous alternative models, providing organisations with diverse options tailored to their specific needs and characteristics.

European Union (EU) legislation requires food operators to demonstrate evidence of an appropriate food safety culture (Regulation (EU) 2021/382 of 3 March 2021), making this a critical issue for the food industry. The implementation of a food safety culture is expected to enhance product quality. A more mature food safety culture correlates with better product quality, in terms of microbiology and overall food safety output levels. This improvement is attributed to various components of Food Safety Culture, including food safety management systems and a positive safety climate (Spagnoli, P., et al., 2024).

When selecting the best safety culture maturity model to apply in the industry, it is important to consider the specific context that organisation is living in. For example, monocultural or multicultural environments may yield different outcomes due to the impact these factors can have on human behaviour, particularly regarding blame and safety perception (Siuta, D., et al., 2022).

The maturity assessment should reflect the organisation's current safety culture level and identify its stage in the safety culture development process (Pei, J., et al., 2023). A well-integrated safety culture system helps prevent errors, incidents, accidents, breakdowns, and cyber-attacks, while promoting safe behaviours even in emergency situations (Siuta, D., et al., 2022). Each organisation must decipher which strategies and tools they should use to evolve progressively from stage to stage.

1.19.2 Framework for Assessing Safety Culture Maturity

Selecting the appropriate safety culture maturity model depends on the specific context and needs of the industry. A model does not need to be a hermetic tool; combining different approaches can provide a richer, multidimensional understanding of safety culture.

To assess the safety culture maturity of the food industry pilots of AGILEHAND, several steps were undertaken. Data from pilots was collected and systematized to determine the safety culture maturity level. The Bradley Curve stages were selected due to their simplicity and widespread use in organisational context. The Bradley Curve serves as a metaphor for the development of safety culture within organisations, with each stage representing an evolutionary phase.

Initially, organisations operate without a formal safety system, relying on instinctive, reactive responses. Over time, habits form, and the standard approach becomes "doing things as they've always been done". Rules and procedures are implemented to drive improvement, requiring constant supervision to establish new habits. This dependent system relies on adherence out of obligation – safe behaviour is adopted because it "must" be adopted.

As the organisation progresses, individuals internalize and understand the previously imposed rules. Supervision becomes unnecessary, and team members act independently and responsibly, demonstrating a proactive approach. Eventually, the organisation reaches a stage where individuals are fully engaged and committed to the well-being of themselves and others. Collaboration becomes second nature, and the team works collectively towards the shared goal of continuous improvement. This vision reflects an integrated safety culture interconnected with the organisation's dynamics, and showcasing varying levels of engagement – from minimal involvement to full commitment.

Based on the literature, a semi-qualitative analysis was defined to evaluate the safety culture maturity of pilots. For this analysis, seven domains were identified to reflect key organisational areas.

As part of the AGILEHAND project, which introduces new technology to traditional food industries, the adaptation of workers' behaviour is a relevant aspect to consider when defining domains, developing indicators and establishing correspondent criteria. However, the framework also incorporates elements from established models, such as Fleming's focus on the impact of quality and Reason's emphasis on the integration of human and organisational factors. Based on these considerations, the indicators were created.

The next step involved establishing criteria by cross-referencing the indicators of each domain with the stages, generating a matrix to facilitate a semi-qualitative analysis. This approach provided a structured evaluation of the organisation´s safety culture maturity.

Annex I presents the complete matrix used to classify indicators and determine the organisations' current stage of safety culture maturity. The framework is structured as follows:

1. Stages

Represent the evolutionary phases in which the organisation can be integrated, progressing from lower to higher levels of maturity: Reactive, Dependent, Independent and Interdependent.

2. Domains

Key areas providing an overview of the organisation's safety culture: Leadership and Management Commitment, Teamwork, Workers Safety Behaviour, Facilities, Equipment and Environment, Communication and Reporting, Training and Awareness raising actions and Safety Management.

3. Indicators

Key aspects of each domain assessed using specific quantitative and/or qualitative data related and relevant to that domain.

4. Criteria

Cross-references the stages with the indicators of each domain, providing a clear definition for each stage within each indicator. This simplifies data classification and establishing boundaries for evaluating collected information.

5. Classification

Assigns the current maturity level to each indicator, ranging from 1 (reactive) to 4 (interdependent).

6. Calculation

Determines the overall maturity level for each domain:

Domain Maturity Score = ∑ Indicators score / n

Where:
∑ Indicator Scores = Sum of all indicators scores within the domain
n = Total number of indicators in the domain

7. Results

The results provide an overall snapshot of the safety culture maturity at the time of assessment, highlighting areas that would benefit from targeted improvement strategies.

The most significant shift in safety culture maturity occurs during the transitions from the second stage (Dependent) to the third stage (Independent), representing the passage from mandatory compliance to voluntary commitment. At this point, management ceases the exertion of pressure, instead fostering integration, empowerment and identification among workers. From the Independent stage onward, organisations demonstrate readiness to embrace the future and adapt effectively to new challenges.

However, as organisations are dynamic and constantly evolving, the various domains do not necessarily progress uniformly. Some domains may be more developed than others within the safety system, reflecting the complexity of organisational growth.

The domains fall under three distinct segments: Human, Organisational and Work Environment, as mentioned before in the context of Safety Culture. Once the safety culture maturity level is determined, efforts can focus on the segments or domains identified as weaker. Targeted strategies can be adopted and adjustments made to enhance these areas, enabling the organisation to progress towards a more advanced safety culture maturity level.

Case Studies on Production and Technology

The following case studies explore vegetables, fruit, meat and fish industrial sectors. These case studies address the diverse operational methodologies, and their corresponding technological requirements related to the classification, handling, packaging, traceability and reconfiguration of production lines for soft and deformable products. The aim is to ensure that all relevant aspects are thoroughly studied to understand the impact of human-AI technologies and draw conclusions that will assist in the identification of requirements and best practices.

These case studies examine how companies and their employees within the analysed industries operate, and the changes ensue with the introduction of AGILEHAND AI technology into these pre-established work systems, in terms of Human Resources, the adaptation of Occupational Safety and Health management, and Communication and Engagement strategies.

In OSH specific context, the AGILEHAND project explores how SMEs restructure and adapt to transitioning toward more automated work methods – the analysis of the implementation process is ongoing and will be concluded in the v.02 of this Handbook.

The proposed framework for assessing the maturity of safety culture is used in two of the pilot cases involving food processing organisations (berries and fish). The accuracy of the results depends significantly on the quantity and quality of the information provided for analysis. For some of the indicators, insufficient data was available, leading to their exclusion. Additionally, the results are only as reliable as the responses provided by the participants in the pilots' studies.

Due to the sensitivity of data, Sant'Orsola and Produmar case studies present only the aggregated results of the analysis. These results were derived from interviews, questionnaires, surveys, on-site observations and accident analysis. This data collection allowed for a comprehensive evaluation of the current OSH system.

Two of AGILEHAND pilots, namely Multiscan and Marelec, are manufacturers of equipment for the food industry. While they do not provide information regarding the production operators, they play a role in establishing a baseline for essential equipment design and installation requirements.

In addition to the typical risks associated with traditional industries, more digitalised equipment necessitates investment in functional safety and consideration of external threats, such as cyberattacks. These vulnerabilities could manifest as loss of process control or malicious actions by hackers, posing significant safety risks.

Suppliers are at a development threshold, facing the challenge of rapidly adapting to the pace of industrial advancements while maintaining a focus on safety and quality, delivering high-quality products that promote well-being, and are user-friendly and easy for workers to adapt to.

The present case studies aim to identify ways in which manufacturers can improve their process to facilitate the industry's transition to automation. These organisations conducted a survey with 26 open-ended questions, administered to five support engineers, each. This approach was taken due to the inability to use information from the end-users of the equipment, as doing so could breach data protection regulations.

1.20 Sant'Orsola: Redefining Small Fruit Production Through Automation and Human-Centric Practices

For more than forty years, Sant'Orsola, an agricultural cooperative emphasising small fruit production, has been a significant participant in the Italian fruit market. This case study investigates the company's path, stressing its original approaches to people management, workplace safety guarantee, and production techniques.

Initially founded in Sant'Orsola Terme, Trentino, by fifteen young growers from the Mòcheni valley, Sant'Orsola has become Italy's top source of tiny fruits. Important turning points define the history of the cooperative:

The innovative Sant'orsola growers first commercialised their strawberry crops in 1972. The Agricultural Producers Association of Sant'Orsola Scarl came into existence in 1975. Beginning in 1981, a new headquarters with warehouses, offices, and storage space started a period of solid expansion. Rising to national leadership in the small fruit industry, Sant'Orsola was named a Producer Organisation by the European Community in 1996.

Creating an experimental field at Vigolo Vattaro in 2002 clearly shows the company's dedication to creativity. Celebrating its 40th anniversary, Sant'Orsola opened "Il Villaggio dei Piccoli Frutti" (The Village of Small Fruits), a new manufacturing facility in 2019. Launched in 2020, the company's most recent invention is a line of Zero Residue goods, therefore creating a distinctive niche in the tiny fruit market.

Sant'Orsola's manufacturing method is marked by a rigorous attitude to excellence and creativity. The organisation's research and development efforts concentrate on creating the best seeds and variants for ideal tiny fruits. Hand-picked, the fruits go straight into baskets on the pitch. After that, they are driven to the logistic hub of "Il Villaggio dei Piccoli Frutti" for a thorough quality check.

In 2020, Sant'Orsola installed an integrated system named InSyeme (Integrated System and Extended Management Evolution) to transform its manufacturing process. This all-encompassing system comprises several novel parts:

- The IDENTPRO System guarantees the choice of the suitable batch for processing, preserving freshness and quality. It also permits real-time monitoring of product stock levels within the storage cells.
- Designed by B2A, a bespoke traceability system linked to every manufacturing line and spans the whole product flow, from processing to storage. This guarantees total traceability and openness throughout the manufacturing process.
- Designed to enable a more ordered and transparent flow of goods and resources, new production layouts help preserve cold chain integrity by lowering the possibility of stocks or shortages.
- Integration of the B-Trace Manufacturing Execution Planning System (MEPS) has allowed daily sales predictions to guide production, optimising personnel presence for efficiency and effectiveness.

Building on these developments, Sant'Orsola has shown even more dedication to technical progress by helping as a pilot firm in the AGILEHAND initiative. This EU-funded project aims to develop improved technologies for independently grading, handling, and packing soft and deformable items. Among the four industrial pilots working on the project, Sant'Orsola concentrates on grading and handling somewhat deformed but very fragile products, especially "berry" fruits.

Mainly in three critical areas, the AGILEHAND project fits rather well with Sant'Orsola's current innovations:

- Smart Sensing Suite: This suite enhances Sant' Orsola's current quality control procedures by using self-calibrating sensing systems to grade fragile fruits' inner and external quality.
- Self-Adaptive Handling, Sorting and Packaging Suite: Building on Sant'Orsola's present handling systems, this suite introduces robotic manipulation systems capable of handling soft, deformable objects without harm based on product quality.
- Agile, Flexible and Rapid Reconfigurable Suite: This suite of AI-based solutions improves Sant'Orsola's current B-Trace MEPS, enabling even more sophisticated monitoring, adaptive control, and production and logistics flow synchronisation.

Moreover, InSyeme's implementation has resulted in an apparent personnel reorganisation. Conventional "capo donne" roles have been replaced with responsible order of production (R.O.P.) roles. These new positions comprise quantitative, qualitative, and informational-managerial components and oversee the running of production orders.

Sant'Orsola went through a thorough selection process and gave the R.O.P. roles thorough training to help with this shift and prepare for integrating AGILEHAND technologies, ensuring that staff members were ready to manage the new organisational model and technology developments.

From a financial standpoint, by accounting standards, the expenditures related to installing InSyeme and engaging in the AGILEHAND project are categorised as long-term expenses and recorded as intangible assets. The anticipated future income-generating and operational efficiencies support this choice.

Using these developments and Sant'Orsola's involvement in the AGILEHAND project, the firm has positioned itself at the forefront of technical improvement in the small fruit sector, improving its operational efficiency, product quality, and customer service capacities. By combining AGILEHAND technology, Sant'Orsola's flexibility, agility, and reconfigurability in production and logistics systems should be even more enhanced, confirming their leadership in that sector.

1.20.1 Occupational Health and Safety

Sant'Orsola is a cooperative, with some of its processes already automated and AGILEHAND is focused on automating tasks within one existing processing line. AS IS (*the initial situation in the pilot, to be reassessed after AGILEHAND technology implementation*), this process is predominantly manual, relying on human operators, which may increase the risk of errors and safety concerns.

The OSH case study was constructed using a questionnaire with 41 open and closed questions about the organisation and a survey of 25 workers, form which 60,00% are women. The survey included 72 questions about health and safety. The sample's worker structure consisted of supervisors (8,00%), grading operators (20,00%), responsible for production orders (44,00%), maintenance operators (20,00%) and other operators (8,00%). 80,00% of the workers' age ranged between 36 to 55 years. The majority (64,00%) had secondary education, while the remaining (36,00%) had medium-level education, corresponding to Levels 4 and 3, respectively, on the European Qualifications Framework (EQF). Additional information regarding risk assessment and maintenance was made provided and an interview was conducted with the union representative and responsible for OSH was held to deepen the analysis.

The production process involves receiving pre-packaged fruit that may require weight and packaging type adjustments. In the first step, boxes are loaded onto a conveyor belt. Punnets are then removed from the boxes and placed on another conveyor leading to a weighing station. Underweight punnets are diverted for weight correction before proceeding to packaging, labelling and manual boxing. Prior to AGILEHAND the delicate nature, lightweight characteristics, and susceptibility to damage of berry fruits made classification, sorting, and handling complex tasks.

AS IS each production line employs seven workers, primarily women, and involves a significant amount of manual labour and loads movement. Risks may arise from the equipment, facilities, organisational rules and workers' behaviour.

Workplace temperatures vary between 4 to 12ºC. While the processing of berries requires low temperatures, these low temperatures can cause thermal discomfort for humans and can lead to health problems if too low or if exposure is prolonged. For example, some operators report falling ill with colds.

The production process relies on conveyor belts that enable the rapid circulation of berries for grading, packaging and labelling. Most risks associated with the equipment derive from the conveyors' movement, which can cause entanglement or pulling, cuts, crushing and friction burns. The equipment also generates noise. Operators may come into contact with electrified components due to system failures or operator negligence, leading to burns or electrocution.

On the production lines, repetitive movements and a fast work pace demands agility and dexterity from operators. There is an established obligation to change workstations every hour to prevent pain and injuries. Despite this, grading and production workers commonly experience back pain and musculoskeletal injuries.

These issues may be related to the production process itself, including repetitive movements, speed demand, load lifting, prolonged standing, twisting, and the fact that workers tend to exert more effort than what is internally defined as safe. For instance, workers may carry more weight than is recommended. Nonetheless, workers generally consider the workplace safe, although they admit that they do not always prioritise their own safety. Colleagues, supervisors, and management point out unsafe behaviour, which workers can correct or disregard if they believe the risk is not significant.

As previously mentioned, seven domains containing several indicators (see Annex I) were used to systematize this case study (see Framework for Assessing Safety Culture Maturity). Figure 2. represents the maturity level of safety culture, illustrating the pilot's status AS IS. The stages are depicted starting from the lowest level of safety culture (Reactive) at the centre of the image, with subsequent levels (dependent, independent, and interdependent) represented outwardly.

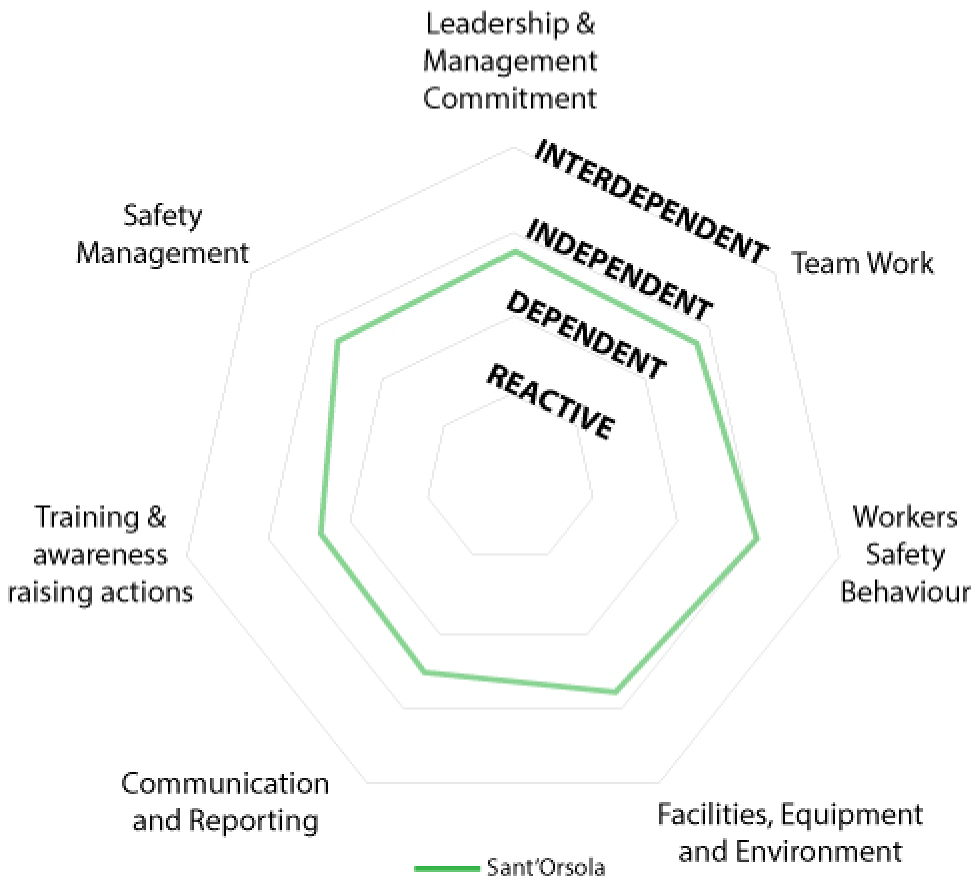

Figure 2. The Maturity Level of Safety Culture in Sant'Orsola

Sant'Orsola can be considered at the Independent level of safety culture maturity. As previously noted, the transition between stages can sometimes be unclear. To consolidate this level, and based on the results obtained, further efforts are necessary, particularly in the areas of "Training and awareness actions" and "Communication and report".

The seasonal nature of berry harvesting presents challenges in maintaining consistent safety activities, worker awareness, and engagement. The discontinuous nature of the work can result in limited training, insufficient communication initiatives, and significant under-reporting of accidents and near misses among workers. To counter this trend, it is important to reinforce regular efforts to ensure that workers are aware, engaged, and prepared to identify risks and adopt safe behaviours. Additionally, encouraging ongoing safety discussions can keep the topic relevant and sustain worker engagement and interest, leading to positive impact on Sant'Orsola safety culture.

Training is always important at the start of each season to provide workers with the knowledge and skills needed to perform their functions safely and respond effectively to emergencies. The effectiveness of these training sessions should be evaluated to ensure the information is correctly transmitted and understood.

Instructions and procedures are an important support to employees in technologically advanced and unfamiliar work environments. Developing missing procedures, high-risk activities procedures, and updating existing ones ensures that workers have access to the necessary information for efficient and safe performance. Outdated procedures should be removed to prevent misuse. Workers must have easy access to relevant, and understandable procedures at their workstations. In multicultural environments, addressing language barriers is essential to facilitate clear communication and understanding.

Establishing clear objectives, allocating a dedicated budget for safety initiatives, streamlining reporting processes for near misses, accidents, and observations, and promoting awareness programs during the plant's operational periods, will contribute to the continuous improvement and strengthening of Sant'Orsola's safety culture.

This analysis still must be completed with the inputs from the impact of AGILEHAND technology in the organisation process).

1.20.2 Human Resources

The strategy used with Sant'Orsola was a methodical and organised procedure designed to facilitate a seamless transition to new technology while optimising employee acceptability and utilisation.

Initial assessment

The first phase was a thorough evaluation of the employees' existing competencies. This essential measure created a definitive baseline of current abilities, offering significant insights for the creation and execution of new technologies.

The competencies identified in the questionnaire applied to Sant'Orsola employees highlight crucial aspects of the social, teamwork and work management skills present in the organisation. The answers provide a comprehensive view of team cohesion, the pace of work and the adaptability of employees, contributing to a deeper understanding of the labour dynamics in the company.

Employees demonstrate strong social and integration skills. The ability to work as a team is evident, with 56% of employees agreeing or totally agreeing that their team is cohesive. This reflects effective communication and collaboration skills, which are essential for achieving organisational goals. In addition, 68% of employees significantly value their colleagues, indicating the existence of solid interpersonal bonds and a positive working environment. Complementing this outlook, 68% also claim not to feel alone in their teams, demonstrating a strong sense of belonging.

Work management emerges as a well-established area of competence. A fast pace characterises operations, with 52% of employees frequently needing to act quickly and 12% reporting this need constantly. This scenario reflects the ability to make agile decisions and carry out actions efficiently. In addition, 72% of workers feel that they often or always have control over their tasks, demonstrating autonomy and proactivity.

Adaptability is also a striking characteristic, with 72% of employees indicating that they often or always feel adaptable, showing resilience and the ability to deal with change. However, high mental effort is a reality for 56 per cent of workers, which shows their ability to cope with complex and cognitively demanding tasks.

Resilience is a significant trait among employees who, despite the challenges, show satisfaction with their jobs and the company. This characteristic reinforces the ability to overcome adversity and maintain consistent performance, even in challenging conditions.

It is important to note that the data reflects the perceptions of a sample of 25 workers, which may not be representative of the entire Sant'Orsola workforce. In addition, the competences identified are based on the answers to the questionnaire and may not cover all the skills essential to the performance of the workers' jobs. However, the results provide a solid basis for understanding the strengths of the team and areas where the company can focus efforts to promote skills development and the well-being of its employees.

Through interviews with union and human resources representatives, it was possible to draw up a detailed profile of the work structure, processes and employee competencies. An organised and methodical work structure was observed, with clear responsibilities for each function, which guarantees not only efficiency but also accountability. The track of production details, such as quantity and operator name, indicates a systematic approach to workflow management and production monitoring.

Identifying Problems and Needs

Simultaneously, a comprehensive study was undertaken to ascertain the challenges encountered by employees and their requirements. This interactive approach guarantees that the technology solutions created are relevant and beneficial to the end users.

The main challenges and needs identified through the questionnaires include difficulties in interpersonal communication, with internal communication being pointed out as one of the main challenges in the workplace. Problems related to working conditions, such as the temperature in the workplace, and organisational issues that occasionally affect the working environment were also highlighted. Only 20% of employees have received training in digitalisation and automation, highlighting the need for development in this area. In addition, adapting to new technologies and systems represents a significant effort for employees.

Specific needs identified include training in new machinery and automation, health and safety training, IT skills development, improved working conditions and more effective internal communication. By addressing these issues and providing comprehensive training, the company can improve employee satisfaction and productivity. Combining skills assessment with the identification of problems and needs has enabled Sant'Orsola to target the implementation of new technologies strategically, ensuring that the solutions implemented are relevant and effective for its employees.

Technology Acceptance Assessment

Following the development of the technologies, the following critical step is evaluating workers' views and acceptance of them. To do this, questionnaires grounded on two known theoretical frameworks will be employed: the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT).

The questionnaire focuses on six key dimensions:

- Perceived Usefulness
- Perceived Ease of Use
- Performance Expectancy
- Expectation of Effort
- Social Influence
- Facilitating Conditions

These dimensions provide a holistic view of the factors influencing the acceptance and effective use of new technologies.

The questionnaires are set to be delivered in January after the workers' orientation and introduction to the new technology. This approach enables participants to develop educated judgements of the tools prior to responding to the questions. This stringent methodological approach not only enables a more seamless and efficient technical deployment but also reflects a dedication to employee welfare and productivity. Sant'Orsola is establishing a robust basis for the enduring success of its digital transformation projects by actively engaging end users throughout the process.

1.21 Produmar: Digital and Human Transformation in the Fish Processing Industry

Established in northern Portugal in 1975, Produmar is a trailblazing family-owned company specialising in seafood cooking and freezing. Over more than thirty years of business, Produmar has become well-known in the market; its success and growth mainly depend on the quality of its products.

Produmar employs 17 people, five directly in the fish processing section. This team comprises women with over twenty years of business expertise. The demographic profile of the employees essentially includes the 46–55 age range and indicates a constant degree of primary education.

Before joining the AGILEHAND project and presenting innovations based on automation, digitalisation, and artificial intelligence, Produmar mainly depended on hand labour for several operations like cutting, sorting, grading, packing, and boxing frozen fish. Some of the equipment utilised in these operations needs to be in better shape, which increases the physical labour required of the staff members.

1.21.1 Occupational Safety and Health

To construct the case study, a questionnaire with 41 open and closed questions about the organisation was administered, along with a survey of 5 workers, comprising 72 questions focused on health and safety. The production line workforce consists entirely of female operators, all handling frozen fish. Of these workers, 80,00% are aged between 46 to 55 years. The workers have primary education, corresponding to Level 1 of the EQF. Further interviews exploring OSH were conducted with the external OSH consultant, two frozen fish operators and a manager.

Produmar is a family-owned SME operating in the food industry. Its production process consists of two production lines operated by five workers. AGILEHAND aims to automate specific stations within the production line, enhancing grading, handling and traceability processes. AS IS (the initial state of the pilot, to be reassessed after AGILEHAND technology implementation), the process relies heavily on manual labour. The frozen fish process begins with cutting the fish into steaks, which are then graded and separated based on classification. The fish is subsequently glazed and packed.

The operators work at fixed workstations and, having been employed at Produmar for over 20 years, have develop substantial expertise in their specific roles. However, this experience has led to reluctance to engage in task rotation. This resistance impedes efforts to implement job rotation strategies aimed at mitigation injuries associated with repetitive work or manual handling. Despite the operators' extensive familiarity with the processes, safety protocols should be available for all functions and risks present in the workplace.

The results suggest that while Produmar values OSH, the company's management approach remains fragmented, lacking a comprehensive and integrated OSH system.

From an ergonomic perspective, the workstations require prolonged static standing and repetitive movements, including rotational and torsional motions, as well as twisted trunk postures, throughout the workday. Although the production process demands rapid task execution, most employees report a degree of control over their work pace, which helps them adapt to the demands and serves as a protective factor against stress, reported as minimal. However, employees acknowledged the cumulative fatigue that develops over time.

The equipment used in the production line presents challenges, some inherent to the equipment and others related to operational practices. The cutting saw poses severe risks, including the potential for serious lacerations. Frozen fish transported along conveyor belts requires manual handling, exposing operators to cold temperatures. At one workstation, an operator must manually remove frozen fish adhering to the equipment's stainless-steel walls, requiring repetitive movements in awkward positions and thus increasing the risk of musculoskeletal disorders. The elevated position of this workstation also introduces a fall risk.

The use of conveyor belts introduces various hazards, such as the risk of entanglement, lacerations or cuts, crushing injuries and friction burns.

Other risks associated with the production line include manual handling of heavy loads, noise, slips and falls. Electrical risks, such as burns, or electrocution may arise from system failures or operator errors.

The work environment is maintained at approximately 8°C to preserve product quality, however, prolonged exposure to such cold conditions can result in thermal discomfort and potential health issues.

An additional concern relates to operator behaviour in response to equipment malfunctions. Workers tend to bypass built-in safety mechanisms of the equipment to expedite issue resolution, leaving the machinery unprotected and increasing the likelihood of contact with moving parts or serious cuts.

Figure 3. represents Produmar's safety culture maturity level, following the same framework as used for Sant'Orsola.

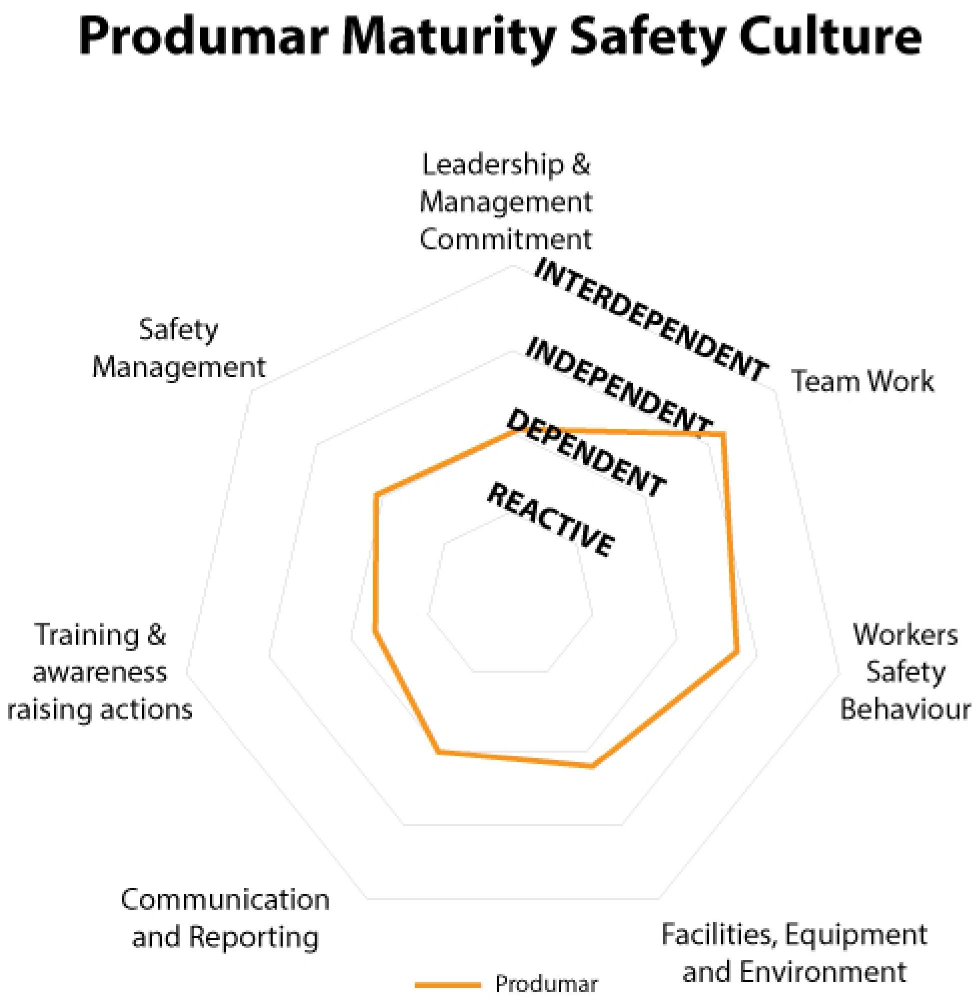

Figure 3. The Maturity Level of Safety Culture in Produmar

Produmar lies in the Dependent stage of safety culture maturity. However, "Workers' Safety Behaviour" and "Team Work" stand out as positive indicators, suggesting progress toward the Independent stage. The familiar environment at Produmar fosters close relationships between employees and managers, creating a sense of camaraderie and commitment to the company's success. Highly motivated workers, with a sense of pride and trust in the organisation and open to change, can positively influence the transition to new technologies in the workplace. A supporting team can be a protective factor among colleagues.

Promoting open communication channels between management and workers, enabling them to express their views and contribute to decision-making processes, is particularly beneficial during periods of transformation, impacting positively safety initiatives and workers' overall well-being.

The current safety culture presents an opportunity for growth by enhancing monitoring and follow-up of risk management, establishing clear OSH objectives and increasing investment in safety initiatives.

An updated and throughout risk assessment enhances safety measures by ensuring that all potential risks are identified and appropriately mitigated. Actively encouraging workers to report unsafe acts, conditions and near-misses provides valuable insights that can help to prevent future incidents. This proactive engagement fosters a more preventive safety culture, contributing to a safer workplace.

Strengthening communication within the organisation by increasing the dissemination of safety-related information, scheduling more frequent training sessions, and introducing regular communication channels, such as newsletters or safety bulletins, can significantly improve the transmission of OSH information to employees. Regularly planning and conducting training and awareness-raising actions ensures that employees remain up-to-date, aware, and competent in OSH matters - particularly when new equipment or operational methods are introduced.

When new equipment is introduced, training is needed for both operators and nearby workers to ensure a thorough understanding of new equipment safety mechanisms, emergency procedures, and associated risks. It should cover system instructions, safety protocols, and potential residual risks arising from unforeseen malfunction or misuse. A blend of theoretical and practical training ensures thorough preparation for interacting with new equipment.

The improvement of existing equipment with advanced technology should start with monitoring and reviewing possible risks and identifying any shortcomings, which should then be reported to the supplier for correction. Understanding how the equipment operates, frequency of preventive maintenance, and how to prevent system failures is critical for ensuring safety and reliability.

While Produmar faces some OSH challenges, addressing these areas will foster the development of a robust and comprehensive OSH system, supporting a safer and more efficient workplace.

(This analysis still has to completed with the inputs from the impact of AGILEHAND technology in the organisation process).

1.21.2 Human Resources

The strategy used with Produmar was a methodical and organised procedure designed to facilitate a seamless transition to new technology while optimising employee acceptability and utilisation.

Initial assessment

The first phase was a thorough evaluation of the employees' existing competencies. This essential measure created a definitive baseline of current abilities, offering significant insights for the creation and execution of new technologies.

Analysis of the responses from Produmar's employees reveals a professional profile characterised by consolidated experience, in-depth knowledge of the tasks and positive interpersonal relationships. All the 5 workers are female and Portuguese with more than 20 years' service in the company, working as “frozen product preparers”. This position involves supervising production lines and preparing frozen fish, indicating a detailed familiarity with the processes and demands of the job.

The responses also highlight a general appreciation of the tasks performed, as well as good relations with colleagues and favourable working hours. These factors suggest a cohesive team with solid teamwork skills and harmonious interpersonal relationships, creating a positive and collaborative working environment. This combination of experience, technical knowledge and good interpersonal dynamics strengthens the team's ability to maintain consistent and efficient performance in Produmar's operations.

Identifying Problems and Needs

Simultaneously, a comprehensive study was undertaken to ascertain the challenges encountered by employees and their requirements. This interactive approach guarantees that the technology solutions created are relevant and beneficial to the end users.

One of the main aspects addressed is physical effort and environmental conditions. The work consists of repetitive activities and exposure to low temperatures, elements that favour physical wear and tear on the workers. In addition, there are recurring complaints about machine noise, which aggravates the discomfort of the working environment.

Another crucial aspect is the perception of risk and its impact on health. Most employees consider their work to be dangerous, and some say that the working environment harms their health. This demonstrates the need for actions to ensure the safety and physical well-being of employees.

Emotional well-being emerges as a concern. Responses about preparation for unforeseen events and emotional stress vary, indicating the need for more individualised support to meet employees' emotional demands.

To summarise, although Produmar's workers have robust knowledge of their jobs and considerable experience, they face significant challenges related to physical effort, environmental conditions and emotional well-being. Therefore, the strategy for implementing new technologies must take these competences and challenges into account to ensure an effective and successful transition, favouring a safer and healthier working environment.

Technology Acceptance Assessment

Following the development of the technologies, the following critical step is evaluating workers' views and acceptance of them. To do this, questionnaires grounded on two known theoretical frameworks will be employed: the TAM and the UTAUT.

The questionnaire focuses on six key dimensions:

- Perceived Usefulness
- Perceived Ease of Use
- Performance Expectancy
- Expectation of Effort
- Social Influence
- Facilitating Conditions

These dimensions provide a holistic view of the factors influencing the acceptance and effective use of new technologies.

The questionnaires are set to be delivered in January after the workers' orientation and introduction to the new technology. This approach enables participants to develop educated judgements of the tools prior to responding to the questions. This stringent methodological approach enables a more seamless and efficient technical deployment and reflects a dedication to employee welfare and productivity.

1.22 MARELEC Technologies: Intelligent Solutions for the Food Industry Through AGILEHAND

Established in 1983 and headquartered in Nieuwpoort, Belgium, MARELEC Food Technologies has become a top producer of intelligent portioning, weighing, and grading systems for the food processing sector. Emphasising poultry, meat, seafood, and maritime industries, MARELEC has developed a reputation for providing creative, premium solutions that maximise production and efficiency for food processors worldwide.

Starting its journey by developing traction control systems for fishing boats, the company laid the foundation for their understanding of marine electronics. Over time, MARELEC expanded its product range. In 1991, it introduced motion-compensated marine scales and began investigating land-based companies like chicken and meat processing. When MARELEC was challenged to create a portioning machine for salmon in 2007, it was a significant turning point since the MARELEC PORTIO launched in 2008. Cutting fixed-weight parts independent of the product's shape transformed the sector, significantly increasing efficiency and lowering waste.

MARELEC's R&D facility and chilled demo room in their contemporary manufacturing base in Belgium reflect their commitment to creativity. Sales and service centres in Europe, the United States, and Asia support the company's international presence; a network of distributors spanning six continents and in more than 50 countries completes this picture. MARELEC's great reach enables them to provide consumers all over localised service and fast delivery.

MARELEC has recently been leading the way in tackling the difficulties presented by changing customer expectations and market demands. The organisation acknowledges the shift from mass manufacturing techniques towards more adaptable and responsive answers. MARELEC has participated in initiatives such as AGILEHAND, which seeks to create highly flexible, robust, and reconfigurable manufacturing lines that can accurately manage a range of goods.

Key participant MARELEC is part of the AGILEHAND project, which aims to build innovative sensing systems, artificial intelligence-driven product grading, intelligent manipulators for handling soft and deformable items, and enhanced conveyance systems. These developments are meant to increase the general efficiency of food processing processes, reduce downtime, and raise output. This project gives MARELEC a chance to extend their intelligent portioning and grading techniques to include internal product quality assessment, thereby lowering human error and enhancing the objectivity of product evaluation.

1.22.1 Occupational Health and Safety

MARELEC Food Technologies specializes in developing advanced portioning, weighing, grading, and control systems for the global food industry. These machines use advanced scanning technology to analyse food, such as chicken breasts, before precisely slicing them into desired weight segments. Additionally, to intelligent portioning machines, also offer innovative weighing and grading solutions. The organisation oversees every aspect of production lines, from design, including tailoring machines to the customer specification, to installation, operation, and maintenance.

Mechanical engineering and Research and Development (R&D) teams collaborate closely to create safe setups where moving and rotating parts are protected, ensuring operator safety and maintaining hygienic, open structure designs suitable for frequent cleaning processes in the food industry, as keeping the device as hygienic (open structure) as possible for cleaning processes that are frequent in food industry.

When introducing new devices, service engineers and internal R&D teams collaborate on prototype testing and demonstrations. Safety features are carefully integrated, for example, in cleaning mode, belts operate at slower speeds, and knives are disabled. This process can be further improved by programming conveyor belts to stop completely during any type of intervention, such as cleaning and maintenance. Safety sensors and Programmable Logic Controllers (PLCs) are embedded to ensure safe operation. Additionally, future maintenance should be considered during design, ensuring provides sufficient space and accessibility to facilitate repairs.

Service engineers possess mechanical and electrical qualifications. As the industry increasingly adopts digitalised systems, software knowledge is becoming an area for development, particularly with the implementation of AGILEHAND's state-of-the-art features to complement existing equipment. New engineers undergo internal safety training as well as external safety preparation training before their first field assignment. The onboarding process includes thorough preparation, enabling new hires to manage service interventions independently.

Service engineers mechanically assemble and test the equipment following installation manuals and checklists. They also train customers, including production operators, maintenance technicians, and production managers, on safely operating and cleaning the machines. Additionally, they provide maintenance training and supply manuals. However, it is suggested that the safety training provided is inconsistent among engineers and lacks proper planning, particularly regarding the allocation of time and participants enrolling. Currently, engineers determine the training content and delivery method rather than following a standardized internal guideline. Such guidelines should be developed through a detailed analysis of key training components and continuously updated based on end-user feedback to improve their effectiveness.

For tailored updates on existent equipment, primarily electronic components, Marelec provides internal notes and instructions to guide the costumer.

To enhance customer support and operational efficiency, Marelec could consider providing videos and resources on a cloud-based platform to allow workers easy access to easy-to-follow training material whenever needed, developing intuitive and user-friendly interfaces for equipment operation and implementing an easily accessible option to change languages, especially beneficial in multicultural environment.

This analysis still must be completed with the inputs from the impact of AGILEHAND technology in the organisation process.

1.23 Multiscan Technologies: Advancing Agri-Food Innovation Through New Technology

Multiscan Technologies is a forward-thinking business specialising in creating and producing vision technology tools for fruit and vegetable sorting and inspection. A pioneer in the agricultural industry with more than 20 years of expertise, Multiscan provides distinctive solutions built on 360-degree product analysis. The company's fundamental values are four: customer, creativity, global reach, and sustainability.

Running under the Duravant family of companies, Multiscan offers food processing, packaging, and material handling services. Their method of developing modern answers for specific customer needs shows their creative bent. Multiscan guarantees consistent help for its clients through a broad network of agents, distributors, and technical services, ensuring its worldwide presence throughout five continents.

1.23.1 Occupational Health and Safety

Multiscan core expertise lies in equipment to fresh vegetables food industry. They produce inspection machines designed for grading and sorting. Their focus extends to a diverse range of vegetables and fruits, such as oranges, lemons, tomatoes or avocado, each with unique shapes and consistencies. Currently, the set-up and calibration process is manual, but AGILEHAND is set to transform that.

When installing equipment, support engineers are involved and provide technical assistance. Equipment complies with European Directives and main International Standards.

When installing an equipment Multiscan provides instructions on the equipment maintenance, adjustments, installation, transportations practices, cleaning manual, as well as user manual explaining how to interact with the software to maximize the equipment's features. The safety training provided to costumers primarily covers basic electrical and mechanical hazards, though it could be expanded.

Multiscan technicians consider that clients generally express satisfaction with the training provided, although it takes some time for operators to adapt to the new equipment and could benefit from additional, more comprehensive training. Practical, hands-on training at client premises is encouraged to enhance understanding.

Service engineers are qualified in mechanical and electrical engineering. However, with the growing integration of digital technologies, additional training in programming software would be beneficial. Improved user interfaces could also help future users to adapt more quickly, increasing overall satisfaction with the equipment.

An OSH technician from a food industry experienced in implementing automated processes, observed that training and information provided by suppliers during automation transitions were often inadequate. Operators felt unprepared due to gaps in specific details, increasing the likelihood of mistakes. Practical, hands-on training at client premises enhance understanding. The technician also noted issues with equipment safety, including the absence of emergency signs, improperly labelled buttons, and, in some cases, missing safeguards for moving parts, rendering the equipment unusable until these issues were addresses. Manufacturers can improve their processes by addressing these issues.

This analysis still must be completed with the inputs from the impact of AGILEHAND technology in the organisation process.

1.24 AGILEHAND solutions providers' point of view regarding strategies for workers' skills development analysis of workers' risks associated with AI and robotic systems

Two different surveys have been conducted involving AGILEHAND solutions providers with two objectives:

- to understand the workers' skills and engagement strategies necessary for using the AGILEHAND solutions.
- to understand the workers' risks associated with the AGILEHAND solutions.

It is useful to present the perspective of AGILEHAND's solution developers as well for several reasons. First, they know the solution better than anyone else, having developed it, and thus, they can more easily point out the risks to operators and the skills needed to use it. Also, product manufacturers are interested in the safety aspects as they are obliged to comply with specific national regulations when developing robotic or artificial intelligence-based solutions.

Four questionnaires have been developed: two to analyse the AGILEHAND scenario of workers' skills and engagement and two to analyse the AGILEHAND scenario of workers' risks.

A Likert scale was applied for each item from 1 point (totally disagree) to 5 points (Totally agree), indicating the level of consensus with the proposed sentences. All AGILEHAND solutions developers have been involved in this survey. These questions have been posed to the designers of the AGILEHAND solutions. All designers involved have more than 5 years of experience in this research field. Moreover, at least one designer for every AGILEHAND solution has been involved. Data were collected from AGILEHAND partners via a combination of regular e-mail and Internet-based survey methods, using a specially developed Internet-based questionnaire. A total of 12 completed surveys were returned. In the next two sub-sections, the results obtained will be presented.

1.24.1 Strategies for Workers' Skills Development and Engagement: the AGILEHAND project solutions' developers' point of view

The first questionnaire analyses in detail whether AGILEHAND solutions shall modify actual and future work processes and procedures, whether AGILEHAND solutions shall need new workers' skills for executing the roles and tasks associated with work processes and activities, whether AGILEHAND solutions shall enhance new workers' skills for executing the roles and tasks associated with work processes and activities, and what new workers' skills will be needed. Table 1 shows the average values and standard deviation.

Table 1. Descriptive statistics regarding AGILEHAND solutions' impact on workers' skills

AGILEHAND solutions impact workers' skills	Average	St. Dev.
Your AGILEHAND solution shall modify actual and future work processes and procedures	4,667	0,492
Your AGILEHAND solution shall need new workers' skills for executing the roles and tasks associated with the work process and activities	3,5	1,004
Your AGILEHAND solution shall enhance new workers' skills for executing the roles and tasks associated with work processes and activities	3,167	0,717

The solution developers could select one, more than one or no skills for every class. Figure 4 shows which skills will be needed for using AGILEHAND solutions.

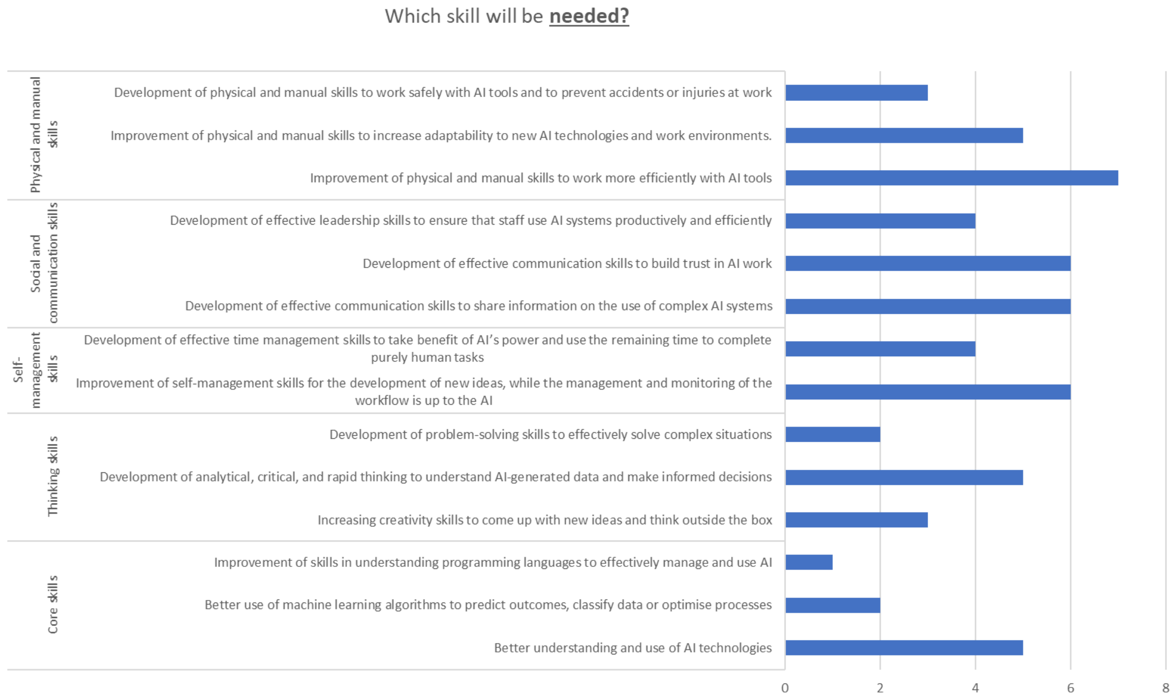

Figure 4. Workers' skills needed in the AGILEHAND context

In the next step, we analysed which skills would be enhanced by AGILEHAND solutions. For this step, we used the same classification already used for analysing the needed skills. The results are shown in Figure 5.

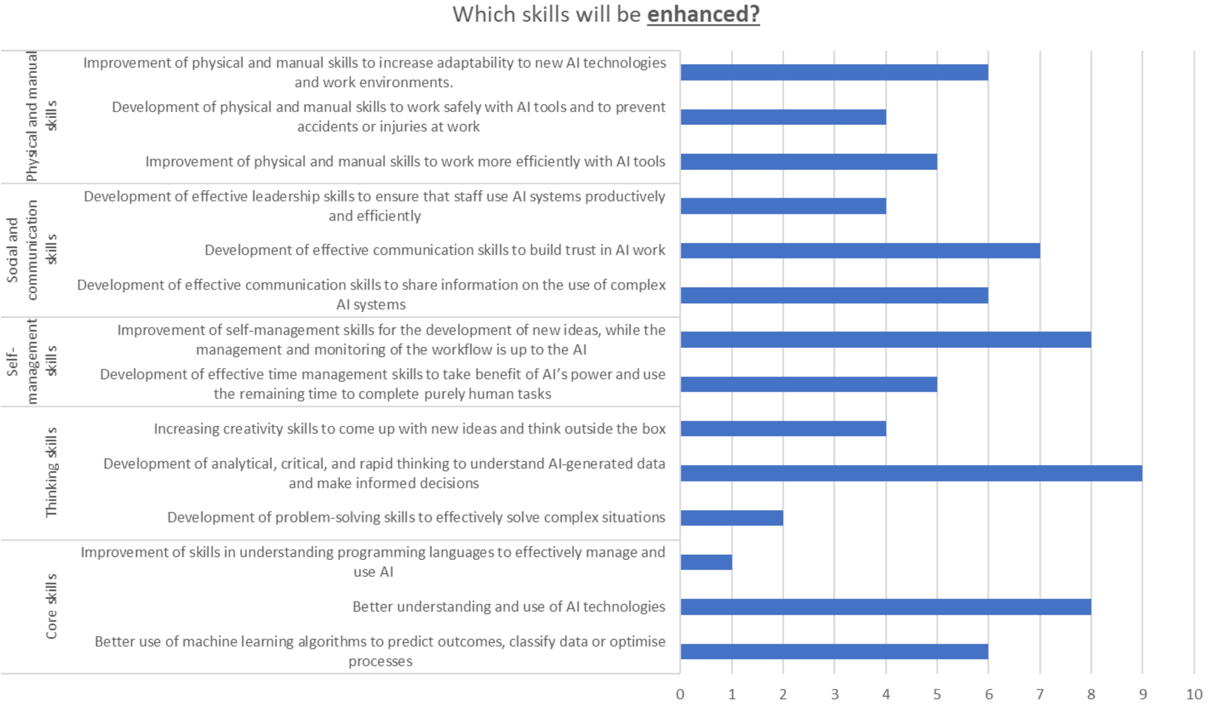

Figure 5. Workers' skill enhanced in AGILEHAND context

The second questionnaire was focused on workers' engagement strategies for AGILEHAND solutions. Table 2 shows the results in terms of average and standard deviation values.

Table 2. Descriptive statistics regarding AGILEHAND engagement strategies

AGILEHAND engagement strategies	Average	St. Dev.
Your AGILEHAND solution shall avoid Surveillance and Privacy Concerns	4,08	1,164
Your AGILEHAND solution shall avoid Job Quality Reduction	3,92	1,240
Your AGILEHAND solution shall avoid Worker Surveillance and Control	3,67	1,230
Your AGILEHAND solution shall avoid the Disruption of Traditional Work Models	3,33	0,492
Your AGILEHAND solution shall avoid Psychological Stress	3,83	0,937
Your AGILEHAND solution shall avoid Loss of Human Connection	4,17	0,717
Your AGILEHAND solution shall avoid Loss of Professional Identity	3,75	1,215

1.24.2 Analysis of Workers' Risks Associated with AI and Robotic Systems: The AGILEHAND project solutions' developers' point of view

Two questionnaires were developed to define the AGILEHAND scenario of workers' risks. The first questionnaire analyses the risks of AGILEHAND solutions connected with implementing AI-based tools. The second questionnaire focuses on risks connected with implementing robotic solutions.

1.24.2.1 Work Risks Associated with the AGILEHAND AI-based Solutions

The first analysis consists of the AI-based solution developers' opinions regarding the impact that their solution could have on workers' risks.

Table 3. Descriptive statistics regarding AI-based solutions risks

AGILEHAND engagement strategies	Average	St. Dev.
Your AGILEHAND solution allows the company the elimination of reoccurring and monotonous working tasks	4,66	0,492
Your AGILEHAND solution allows the company to remove activities in a hazardous work environment	2,66	0,984
Your AGILEHAND solution allows the company to reduce the risk of occupational diseases	2,33	1,154
Your AGILEHAND solution shall handle or circumvent hazardous situations occasioned by user misuse	2,50	1,167
Your AGILEHAND solution shall avoid Job Displacement	3,33	1,435
Your AGILEHAND solution shall avoid Dependence on AI Systems	3,16	1,114
Your AGILEHAND solution shall avoid Cybersecurity Vulnerabilities	4,25	0,866

1.24.2.2 Work Risks Associated with the AGILEHAND Robotic Solutions

The last step of this study concerned the Robotic solution developers' opinion regarding the impact that their solution could have on workers' risks.

Table 4. Descriptive statistic regarding Robotic solutions risks

AGILEHAND engagement strategies	Average	St. Dev.
Your AGILEHAND solution allows the company the elimination of reoccurring and monotonous working tasks	4,75	0,452
Your AGILEHAND solution allows the company to remove activities in a hazardous work environment	2,91	1,378
Your AGILEHAND solution allows the company to reduce and simplify work with heavy loads	2,50	1,243
Your AGILEHAND solution allows the company to reduce the risk of occupational diseases	2,33	1,230

AGILEHAND engagement strategies	Average	St. Dev.
Your AGILEHAND solution allows the company to reduce unilateral physical workload	2,75	1,356
Your AGILEHAND solution shall handle or circumvent hazardous situations occasionated by user misuse	2,41	1,443
Your AGILEHAND solution shall avoid Job Displacement	4,16	1,267
Your AGILEHAND solution shall avoid Cybersecurity Vulnerabilities	4,25	1,138
Your AGILEHAND solution shall avoid Safety Hazards	4,40	0,699
Your AGILEHAND solution shall avoid Ergonomic Issues	4,08	0,668
Your AGILEHAND solution shall avoid Worker Surveillance	4,33	0,492
Your AGILEHAND solution shall avoid Dependence on Robotics	3,08	1,311

1.24.3 Conclusion

The AGILEHAND project offers a valuable examination of how robots and artificial intelligence influence workers' talents, participation, and potential workplace problems. With the help of experienced solution developers, the study paints a clear picture of how work processes are changing and what skills are required to adapt to these new technologies.

The study emphasises that AGILEHAND solutions are probably going to change current work processes and procedures, therefore new skills development among employees is very necessary. Fascinatingly, the solutions are also supposed to improve certain worker skills, especially in areas like technical competency, problem-solving, and decision-making.

Regarding worker involvement, the research underlines the need of good communication, appropriate instruction, and encouraging of a favourable attitude towards these new technologies. It is encouraging to see the developers understand the requirement of a human-centred approach for applying these sophisticated technologies.

Still, things aren't always perfect. The research also clarifies possible hazards connected to both robotic and artificial intelligence-based solutions. These include worries about employment stability to the psychological and physical effects on employees. The fact that the developers are aware of these hazards and probably thinking on strategies to minimise them is comforting.

When seen holistically, this study depicts a changing workplace. Even if there are hurdles to overcome, there are several chances for advancement. As technology advances, we must continue to value the human aspect. After all, it's not just about improving the equipment; it's also about developing a workforce that can operate alongside it.

Best Practices and Lessons Learned

Characterised by the integration of modern technologies like robotics, artificial intelligence, and the Internet of Things, Industry 4.0 has started a new era in manufacturing. This digital change provides production capacity, efficiency, and more freedom. Still, it also presents significant challenges, particularly about operational integration, workforce flexibility, and safety issues. It is crucial for industrial organisations embarking on the digital journey to identify and adopt best practices that facilitate a seamless transition and optimise the advantages of technology breakthroughs. We thoroughly reference best practices for adopting Industry 4.0 in industrial settings, synthesising insights from significant literature studies and in-depth interviews with key players. It covers essential themes, including leadership characteristics, instructional tactics, safety procedures, human-centred methodologies, team development strategies, and socio-technical integration.

1.25 Health and Safety Approach

- Workers involvement from the beginning, for example including tests with the new technology.
  - Design Out Hazards: Focus on minimising or eliminating hazards during the design or implementation phases of new technologies (Leso et al., 2018).
  - Social-technical approach to implementing digitalisation and automation in organisations, fostering a synergy between organisational, professional and technical development (Polak-Sopinska, et al, 2020).
  - Collaborative Risk Assessment: Involve employers, employees, stakeholders, and occupational health professionals in defining new technologies potential impact on work practices, employment, and OSH (Leso et al., 2018).
  - Preventive Maintenance: Implement well-planned, accessible maintenance processes for all employees interacting with robotic equipment. This proactive approach enhances safety and system longevity.
  - Automated Fault Detection: Deploy systems capable of alerting workers to potential dangers, coupled with clear signage identifying button functions.
  - Pre-installed Safety Features: Ensure machines are supplied with all required safety features pre-installed, allowing for immediate commencement of operations without post-installation safety adjustments.
  - Material Selection: Carefully select materials considering the work environment and resistance to cleaning products.
  - Supplier-Customer Collaboration: Provide clear, throughout instructions and ensure training to the end-users. Share best practices in a mutual beneficial two-way dialogue. Testing robot positioning and correct functioning (Steijn et al., 2016).
- Continuous Improvement: Implement improvement cycles to raise process standards, addressing shortcomings, mishaps and failures during all process of implementation and operational phase (Steijn et al., 2016).

1.25.1 Regulatory Compliance

- Enhanced Information: Ensure machine manufacturers provide comprehensive information about robotic systems and safety measures.
- Regular Risk Assessments: Regularly update risk assessments to include hazards associated with new automated equipment.
- Regulatory Compliance: Ensure equipment complies with safety regulations and workers are fully trained in safe practices.

1.25.2 Collaboration and Communication

- Multidisciplinary Approach: Advocate for an interdisciplinary team to analyse the entire lifecycle process and establish effective communication between technology developers, programmers, and end-users.
- Early Worker Involvement: Involve workers early to ensure they feel included and valued, reducing resistance to change.
- Continuous Dialogue: Maintain ongoing communication between management and workers to address concerns regarding job displacement.
- Balanced Human Interaction: Maintain human interaction alongside automation to preserve meaningful social relationships in the workplace.

1.25.3 Training and Skills Development

- Comprehensive Training: Provide detailed, practical, and ongoing training for workers to adapt to new systems.
- Upskilling Focus: Emphasise upskilling employees rather than replacing them, fostering job security and growth.
- Safety Training: Address knowledge gaps, particularly in safety practices related to new technologies.

Future Outlook

This section will be done in v2 of the deliverable.

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Annex I

Safety Culture Maturity Framework Criteria

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
Leadership and Management Commitment	1. Establishment of a safety vision, objectives and policy	Inexistent vision, objectives and policy or not implemented.	Basic vision on policy in place, but not well-integrated. Occasionally might have mostly negative safety objectives framed as something to avoid or prevent, that are not always or seldom implemented.	Clear internally developed vision and policy. Definition of yearly safety objectives.	Shared vision on safety that includes all aspects of daily work, between Management and Employees. Defined objectives, Key Performance Indicators and an allocated budget. Objectives framed as something positive to strive to achieve.
	2. Personal involvement in safety activities	Safety activities do not exist.	Safety activities are seldom and with low participation and involvement.	Management demonstrates active support for safety initiatives and participates in some.	Strong commitment to safety is notably a core value at all levels of the organisation. Evident time and effort allocated to safety issues and activities.
	3. Worker's involvement in safety-related decisions	Workers are not involved by Management in the decision-making process for safety issues.	Workers might be consulted by Management on safety issues, and sometimes their opinions are considered in the decision-making process.	Workers are consulted by Management on safety matters, and their opinions are considered when making decisions.	The decision-making process is flexible, depending on the urgency of the decision and the expertise of those involved. Workers are consulted by Management and participate actively in decision-making. Encouragement of a sense of ownership.
	4. Trust, respect, inclusion and transparency	Limited importance given to these values. Management strictly instructs workers on what to do and how to do it.	These values are promoted and sometimes put into practice. Decisions on tasks and methods are predominantly made by management, with minimal worker involvement.	These values are actively promoted and frequently practiced. Workers are empowered to make some decisions on how to reach goals, fostering a sense of engagement.	Management is open and honest with the team, creating an atmosphere of trust in which employees are encouraged to provide safety-related information. Goals and objectives are set, allowing for complete freedom for workers to provide input on how to achieve them.

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
Leadership and Management Commitment (cont.)	5. Recognition	Little to no recognition for safety efforts	Recognition based on compliance with rules	Regular recognition for proactive safety initiatives	Comprehensive recognition system that reinforces safety culture
	6. Commitment to continuous safety assessment and improvement of safety practices	No assessment conducted or only after incidents.	Regular assessment take place, but limited follow-through on improvement actions.	Ongoing assessments with clear improvement plans. Improvement of production processes to be safe. Going beyond compliance.	Proactive and continuous improvement deeply embedded in organisational practices. Willingness to adapt. And provide resources for safety. Safe production processes in place. Human and material resources that ensure safety.
	7. Risk behavior tolerance level	High tolerance to risk behaviour.	Management and supervisors enforce safety rules and regulations.	Low tolerance to risk behaviour. Unsafe behaviour is often addressed.	No tolerance for risk behaviour. Unsafe behaviour is addressed.
	8. Prioritization of safety	Productivity is the main organisation focus.	Productivity is the focus, however there is some compromise with safety.	Productivity and safety are both important, and workers can decide to stop without repercussions if a task doesn't offer enough safety.	Priority to safety over anything that can potentially compromise it. The allocation of necessary resources is reflected in every organisational aspect: e.g. rest time, shifts, tools and technology used. Relationship between safety and production efficiency is correctly handled.
Team Work	1. Ownership of safety in workplace	Workers do not consider themselves responsible for the safety of their colleagues and fail to intervene when identify unsafe acts or conditions involving the team. Blame of external factors, colleagues or others, for injuries.	Worker’s involvement in the safety of the team is driven by obligation rather than a sense of responsibility.	Actively engage in promoting a culture of safety within their teams, intervening when detecting an unsafe act or condition.	Embrace team safety and take deliberate actions to address co-workers unsafe acts or conditions often times preventively sharing their observations or concerns. Consistently uphold mutual accountability for maintaining safety standards. Proactive action to prevent incidents for themselves and others. Collective efficacy in maintaining safety.
	2. Shared vision, trust and	No collective vision or effort towards safety goals.	No collective vision and limited effort towards safety goals.	Collective alignment and individual efforts towards safety goals, contributing to create and	High collaboration, mutual support and shared safety vision in a trust-based approach.

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
Team Work (cont.)	collaboration on safety			maintain a safe work environment.	
	3. Safety discussions	Safety is not a subject of conversation.	Safety is sometimes a topic of conversation.	Safety discussions are encouraged and take place regularly.	Workers have autonomy and engage in frequent constructive discussions about safety practices and concerns.
	4. Interactions with supervisors and peers	Supervisors address safety when there is an incident. Peers often disagree on safety issues.	Supervisors alert workers and support them on safety issues. Peers mostly agree on safety priorities.	Supervisors proactively prioritize employees and system safety, promoting a safe environment. Peer support for safety initiatives is strong.	Fellowship. Clear lines of accountability and authority.
Workers Safety Behavior	1. Risk perception	Limited perception or misperceptions of the seriousness of risks, leading to unacceptable decisions and danger behaviour.	Misjudgement of risks, often underestimated, sometimes resulting in poor decisions and risk behaviour.	Good awareness of potential hazards. Focus on prevention.	High-risk perception, where risks are actively anticipated and managed. Focus on prevention and safety promotion.
	2. Knowledge of procedures and competence on safety overall measures	Limited knowledge and respect for procedures. High number of unsafe acts.	Basic knowledge of procedures not always applied.	Procedures standardize operations during routine conditions and are part of daily operations, understood and applied by all.	Workers demonstrate comprehensive knowledge of procedures, safety expertise and skills. Autonomy and know how to manage threats or disruptions effectively and are overall competent and able to use their knowledge during safety problems.
	3. Initiative and proactivity in safety	Worker's initiative in safety matters is neither promoted nor practiced.	Workers start a preventive action only after a supervisor asks them to.	Workers solve the risks or propose solutions for newly discovered risks.	Workers proactively identify threats to safety and seek changes to mitigate them. They look for ways to simultaneously enhance safety and productivity.
	4. Value perception of safety regulations, rules and procedures	No importance given to rules and procedures.	Safety seen as adherence to established rules, procedures and compliance but not prioritized.	Workers recognize the value of safety procedures as essential to daily operations	Safety is a core value, ingrained in the organisation's culture and actively promoted by workers. Employees know and agree with organisation safety commitment and recognize its importance.

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
Workers Safety Behavior (cont.)	5. Individual priorities	Safety often compromised for convenience or speed. Recklessness behavior.	May take shortcuts when convenient.	Safety is often prioritized in all decisions that have hazards and risks associated. Under pressure safe behavior might be neglected.	Safety is always prioritised in all decisions that have hazards and risks associated. Adoption of proactive safe behaviour at all times, including under pressure.
	6. Organisation pride and trust	No pride. Low commitment and engagement.	Limited pride in organisational achievements. Basic commitment to job duties. Low connection to organisational goals.	Pride in the organisation. Commitment to responsibilities and work towards excellence.	Deep pride. Committed to excellence and enhance their workplace and overall organisation. Job satisfaction.
	7. Safety compliance and responsibility	Resistance to basic safety requirements, procedures, and guidelines. Safety rules seen as unnecessary obstacles. Deliberate disregard for rules to complete tasks.	Inconsistent compliance with safety rules, requiring supervision to ensure adherence. Workers may recognize the personal benefits of safety, but don't assume broader responsibility in its development within the organisation.	Accept and follow safety rules. Maintain safety standards without constant supervision.	Fully integrate safety requirements and rules into daily work routines.
		Reluctance to wear PPE (Personal Protective Equipment) consistently or correctly.	PPE is used irregularly or improperly.	PPE is accepted and worn correctly when required.	PPE use is fully accepted and integrated into workplace, with strict adherence.
	8. Involvement in safety decisions and activities	No involvement in safety decisions and activities. No interest in organisational safety efforts.	Involvement if mandatory. Provides input only when directly prompted.	Willingness to contribute to safety improvements.	Active participation in decisions and initiatives contributing to safety improvement. Proactively provide constructive feedback and suggestions.
Facilities, Equipment and Environment	1. Tools and Equipment inherent safety	Non-conformity equipment and tools or allocated reactively based on incidents.	Equipment safety characteristics are based on regulations and external pressure.	Equipment safety characteristics are prioritized based on regulations and risk assessments. Regular inspection protocols.	Proactive assessment and inspection of tools and equipment safety focus on predict and prevent physical risks through preventive measures and mitigation strategies. All equipment and tools are certified. Continuous improvement.

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
Facilities, Equipment and Environment (cont.)	2. Workplace Environmental Conditions	Illumination, noise, vibrations, temperature and air quality are observed only after an incident or professional disease. Mostly uncomfortable without measures taken to reduce the adverse effects.	Illumination, noise, vibrations, temperature and air quality comply mostly with regulation-imposed values. Uncomfortable with some adopted measures to reduce the negative effects.	Proactive assessment of illumination, noise, vibrations, temperature and air quality and preventive measures adopted for some of these environmental factors.	Illumination, noise, vibrations, temperature and air quality meet or exceed legal values improving workplace conditions. Comfortable to ensure health and wellbeing of employees. Eventual use of technology and data analytics to predict and prevent potential physical hazards.
	3. Ergonomy	Equipment is not ergonomic. Demanding job. Overexertion, overextension. Unawareness of the best postures to adopt while working.	Equipment ergonomy respects regulations, workers might receive some training in ergonomy, although only adopt more favorable postures and movements if supervised.	Equipment ergonomy is assessed and improved based on findings. Workers are aware and adopt ergonomic postures and movements.	Work environment allows free movement, easy access to equipment and materials and adaptability to individual employee needs. Equipment are ergonomic and proactively improvements are implemented. Workers know and adopt ergonomic postures and movements.
	4. Pace of work & workload	High pace and high pressure.	Basic policies to manage work pressure and workload, that might not be consistently applied.	Regular workload and work pressure assessments and (re)adjustments.	Evaluation of task complexity and time requirements to ensure optimal distribution of work. Promotion of work-life balance.
	5. Chemical and Biological risks	Chemical and biological hazards are not systematically identified or assessed. Safety measures are reactive and implemented only after incidents occur. Workers lack proper training on handling hazardous materials.	Some chemical and biological hazards are identified, but risk assessments are incomplete. Basic safety protocols exist but are not consistently followed.	Most chemical and biological hazards are identified and assessed. Comprehensive safety protocols are in place and generally followed. Risk mitigation strategies are implemented for identified hazards.	All chemical and biological hazards are systematically identified, assessed, and monitored. Robust safety protocols are consistently implemented and regularly updated. Workers receive extensive, role-specific training on hazard management.

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
Facilities, Equipment and Environment (cont.)	6. Personal and Collective protections	Allocated reactively based on incidents.	Investment in personal equipment and collective protections is based on regulations and external pressure.	Investment in personal equipment and collective protections is prioritized based on risk assessments.	Proactive investment in personal equipment and collective protections with a focus on preventing incidents and continuous improvement.
		PPE[1] is inadequate to workers or their specific functions.	PPE is available but not always appropriate for the specific risks present.	Proper PPE adaptable to workers and their role.	PPE are tailored to individual needs and regularly updated.
		Warning signs are scarce, outdated or non-existent.	Warning signs exist according with regulations, but some may be in poor condition or incorrectly placed.	Warning signs are present in most necessary areas, regularly maintained and updated as needed.	Warning signs exist in all necessary places, are clearly visible, and regularly verified to ensure they are fully intact and undamaged.
	7. Maintenance	Interventions after mishaps or equipment failures. No systematic approach to maintenance planning.	Planned Maintenance according to minimum regulatory requirements.	Preventive maintenance performed frequently based on manufacturer recommendations and usage patterns. Prompt response to equipment failure, but not always.	Maintenance is preventive and predictive often performed to verify the safety and quality of the equipment. Reply to failures is immediate and equipment is quickly repaired or replaced.
		No record-keeping.	Some record-keeping of maintenance activities.	Consistent record-keeping.	All maintenance information is registered.
		Inexistent safety and quality checks.	Safety and quality checks performed to meet compliance standards.	Regular safety and quality checks are integrated into the maintenance process.	Integration of maintenance planning with safety management systems.
	8. House Keeping	No formal procedures established. Cluttered and disorganised workplace. Aisles, exits, and pathways are frequently obstructed. Spills not promptly addressed.	Basic housekeeping procedures in place but not consistently followed. Some areas remain cluttered. Response time to unpredictable spills may be longer than necessary.	Regular housekeeping practices are established. Pathways, aisles, and exits are generally kept clear of obstructions. Spills are addressed promptly according to clear procedures.	Proactive daily housekeeping practices. No obstructions in pathways, aisles and exists at any time. No clutter policy with designated storage areas consistently respected.

[1] PPE – Personal Protective Equipment

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
					Immediate cleanup in the event of spills.

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
Facilities, Equipment and Environment (cont.)	9. Rest Environment	Unclean and discomforting spaces (e.g. toilets, locker rooms, canteens). Lack of green areas. Overcrowding leading to disconfort.	Basic cleanliness. Limited green spaces. Crowded areas during peak times.	Clean, well-maintained and comfortable rest facilities. Green spaces and outdoor areas available and well-maintained. The number of workers is aligned with the size of the premises.	High standards of comfort and clean spaces. Well-being is enhanced by green areas and relaxation zones integrated into the workplace design. Spacious rest areas, without overcrowding during peaks. May include recreational areas or quiet zones.
Communication & Reporting	1. Communication effectiveness and information flow	Communication and information on safety matters are non-existent or rare, primarily arising from incidents and flowing in a top-down manner.	Safety communication emphasizes a shared commitment to safety objectives, the collective impact of individual contributions and adherence to regulations.	Open communication about safety concerns, with safety as an integral part of every job function. Dynamic exchange of information.	Active Communication. Continuous free-flowing safety dialogue promotes shared responsibility and ownership of safety performance. Good safety information exchange with external parties.
	2. Shared lessons learned	No sharing of safety-related lessons.	Shared to a limited extent, focused on compliance.	Lessons learned are shared every time there is a near-miss or accident.	Proactive sharing of in-house and benchmarked lessons learned to promote safety behaviour and reporting.
	3. Safety newsletters, flyers, posters or other means to foster safety information	No internal communication.	Spread of safety information is once or twice a year.	Information about safety circulates very often. Content is rich and relevant, displayed in visible locations.	Safety information is transmitted constantly through channels such as posters, flyers, banners, bulletin boards and electronic display. Safety materials are in line with the actual production conditions and documents match that concept. Content is rich and relevant, displayed in highly visible locations.

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
	4. Report of accidents, near-misses and unsafe conditions	Under-reporting of accidents and near-misses due to fear of blame and punishment or lack of awareness.	Accidents are reported, when result in medium or serious consequences, while near misses are not reported. Suggestions or feedback for improvement are uncommon.	All accidents are reported, including those that are not serious. Near misses that could lead to more serious consequences are also reported.	Timely, civility and direct reporting of unsafe conditions, near-misses and accidents, with focus on prevention and continuous improvement. Employees feel safe and encouraged to report incidents and hazards.
Communication & Reporting (cont.)	5. Employees voice concerns and suggestions for improvement	Minimal concerns voiced. Fear of reprisal and punishment or lack of engagement or knowledge.	Concerns occasionally voiced but often driven factors unrelated to safety issues.	Employees voice concerns regularly and without fear of reprisal, fostering continuous improvement.	Employees actively engage in improvement suggestions, promoting collaboration for collective safety, while is clear what is acceptable and unacceptable behaviour.
	6. Feedback and response	Feedback is rare, leading to disengagement.	Feedback is provided but lacks timeliness or consistency.	Timely feedback on safety concerns is provided, with actionable steps.	Consistent and constructive feedback leads to improvements in safety practices. Collected data is analysed and safety information is reported and disseminated to employees on a routine basis.
Training & awareness raising actions	1. Training planification	No planification. Safety training is infrequent and reactive to incidents. No transmission of information about hazards.	Planification is irregular or inexistent. Training occurs approximately once a year. Focus is on basic safety procedures, neglecting information about specific hazards and consequent risks.	Training is planned regularly and tailored towards specific roles and hazards, encouraging individual responsibility. Occurs multiple times a year. Convey adequate information about risks. Most of the employees participates in training actions.	Training actions are planned, continuous and integrated into all aspects of work, fostering safety awareness and continuous improvement. Effective methods, adequate duration, and cover of all workplace hazards. Participation is mandatory for all employees, with regular updates and revisions.
	2. Employees knowledge and skills in safety	Training is not effective, and employees have limited or no safety knowledge.	Training is somewhat effective, and employees have basic safety awareness.	Training is effective and employees have good safety and best practices knowledge.	Training is 100% effective and employees have comprehensive safety expertise and skills. Best practices are trained. Necessary knowledge, skills and job experience is provided: employees are familiar with the safe use of the equipment and

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
					respect its inherent safety mechanisms, also know what to do in case of faulty equipment. Know how to use equipment and tools proficiently.
Training & awareness raising actions (cont.)	3. Awareness of safety risks	Awareness raising sessions don't exist.	Some awareness is conveyed.	Awareness sessions are planned and occur frequently. Regular safety briefings cover both general and job specific risks.	Workers understand the hazards and risks inherent in their areas of operation and related with their function. Awareness sessions and briefings happen regularly, and the organisation encourages safety discussions and awareness raisin activities.
	4. Emergency	No emergency training or drills.	Generic safety training. Mandatory drills take place.	Role-specific safety training. Regular drills. Employees are trained and can calmly handle emergency.	Proactive search for emergency knowledge. Feedback about first aid and emergency equipment. Regular drills to sustain the team performance and reinforce workers behaviour.
Safety Management	1. Accidents	High number of accidents. Accidents viewed as inevitable. No investigation off accidents.	Accident rates may decrease slightly and are still thought to be inevitable. Serious accidents are investigated.	Preventive measures implemented and some good practices. Low number of accidents. Moderate and serious accidents are investigated.	Zero accidents policy. If any accident occurs, regardless of its severity, it is thoroughly investigated.
	2. Near-misses	No tracking of near misses.	Poor near-misses tracking.	Regular near-miss reporting.	Comprehensive near-miss reporting.
	3. Personal injuries severity	More than 90 lost days per injury.	More than 30 lost days per injury.	More than 3 lost days per injury.	Three to no lost days.
	4. Ongoing inspections, registration, monitoring of the risk management and follow-up	Relies on external expertise. Only mandatory reports.	Relies on internal and external expertise. Only mandatory reports, with good quality.	Relies on internal expertise. There is commitment with external parties and from external parties. Good quality reports and observations.	Relies on internal expertise and management is involved in results and follow-up actions. Safety Personnel actively exchange information to promote best safety practices and are seen as competent. High quality reports and observations.

Domains	Indicators	Reactive (1)	Dependent (2)	Independent (3)	Interdependent (4)
Safety Management (cont.)	5. Risk Management System	No risk assessment. Workers are not involved in risk identification. High risk levels. Focus mainly on hazards and risks that caused incidents.	A risk assessment exists but is not updated. Limited employee involvement in risk assessment processes.	Risk assessment is updated and reassessed every time a change occurs in the work process, equipment or any other aspect. Workers are involved in risk identification and assessment.	All collaborators at all levels are fully engaged in continuous risk identification and assessment on a regular basis. Risk assessment is updated and periodically reviewed. Emergent problem areas are systematically tracked to reduce or eliminate risks. Each function has specific assessment requirements.
		Corrective measures applied only after the incidents occur.	Mandatory measures and corrective measures implemented.	Preventive measures implemented mostly for high and medium risks.	Preventive measures are taken immediately after identifying a hazard. Individual needs of the employees are considered for they comfort and safety.
	6. Procedures and instructions	No procedures.	Some functions and equipment have procedures.	Procedures are effectively implemented.	Procedures are effectively implemented, and cover all potential hazards and risks, are updated, available to everyone and easy to access and understand. Employees use checklists regularly.

Annex II

The following guidelines provide a framework for safe and compliant operation of robotic systems and AI-based systems encompassing the Design, Implementation, and Operational stages.

Ensuring safety primarily involves thoughtful design, robust robot systems and well-planned workspaces. These guidelines derive from risk assessments, literature, European regulations and safety standards. They are not exhaustive; for a comprehensive approach, Regulations and Standards should be consulted and applied to ensure compliance and the implementation of best practices, thereby assuring the safety and health of workers.

Design

User-Centered Design
The most effective safety by design approach prioritizes user involvement. Users provide valuable insights into their work processes and present hazards, fostering a deep understanding (EU-OSHA, 2018). Early participation is also linked to increased workers' acceptance of the system (EU-OSHA, 2023). Including regulators, unions, managers, and operators in the process ensures that the system meets everyone's needs.

Functional Safety
Functional safety guarantees the safe operation of equipment and systems by minimizing the risk of failures that lead to accidents or injuries, when a safety function is triggered by the control system. A risk assessment is performed, and high risks related to safety functions must be addressed by introducing a control system designed in accordance with safety requirements, which will be validated to check its performance level. Failures result when there is a security breach, deterioration of security function or deviations from the objectives (Anunciação, et al., 2022) and may lead to a hazard or accident.

Risk Assessment
To ensure the safety of users throughout its lifespan, a comprehensive risk assessment is essential. This assessment identifies potential health and safety hazards, including those foreseeable during the equipment, end-effectors and systems lifetime. The design and development process should proactively address these identified risks to eliminate or minimize their occurrence. Risk reduction may result from:

Protection of Moving Parts and Passive Protection – To prevent future incidents from inadvertent contact between human and traditional robot systems, moving parts should be enclosed, if not possible, strong guards or barriers should be installed, to prevent operators from accidentally be pulled, pushed or crushed (Regulation (EU) 2023/1230 of the European Parliament and of the Council of, 2023).

Equipment, end-effectors and other components should be designed with smooth, round edges and corners to minimize the risk of injury and facilitate cleaning. Exposed, sharp or cutting edges, pinch points, and other potential hazards should be eliminated or guarded in all exposed locations within the workstation (Regulation (EU) 2023/1230 of the European Parliament and of the Council of, 2023).

Stop functions – Each workstation should be equipped with a clearly identifiable normal stop button that overrides the start command, allowing for total or partial equipment shutdown. Additionally, equipment must feature clearly visible, identifiable and easily accessible emergency stop buttons. These buttons should have priority over all other operational modes and functions at all times (Regulation (EU) 2023/1230 of the European Parliament and of the Council of, 2023), including during technical malfunctions. Operators must be able to halt the movement of robots at any time with a single action.

Collaborative robots might need one, or more enabling devices to prevent potential collisions between human and robot. Protective measures may include stopping on approach, limiting power and forces, reducing speed, or emitting a sound or a visual alert without creating new hazards (Regulation (EU) 2023/1230 of the European Parliament and of the Council of, 2023).

Food Contact Materials and Cleanability – Materials used in robot or end-effectors, that contacts food, must be smooth and free or concavities that could harbor or accumulate organic materials. They should also be easy to clean and disinfect, and if dismantling is necessary for cleaning, the process should be straightforward. The design must allow equipment and end-effectors to be easy to clean and maintain and ensure that waters from cleaning, disinfecting and rising drains out of the equipment (Regulation (EU) 2023/1230 of the European Parliament and of the Council of, 2023). Materials used in technology solutions must be adequate to contact food and not release hazardous chemicals and chemical products used within the robots, such as lubricants, must not come into contact with food. A handbook should be provided with instructions on recommended products and methods for cleaning, disinfecting and rinsing areas easily accessible and inaccessible.

Durability and Resistance – Materials and components used in harsh environment must be able to withstand cold, water, moisture and salt. Both the materials and conception must ensure that cleaning products do not affect technological performance, as this could increase the risk of system failure and endanger workers. Given the nature of the activities, these factors must be considered to ensure that technology solutions are adequate, offer resistance and are properly insulated and grounded.

System Stability – The system must offer stability to prevent tipping over or falling. This could happen due to mistakes during setup or vibrations while operating.

Prevention of Disruptions – Robot design should prevent electrical, electromagnetic, radio frequency or connection disruptions that can interfere with robot software and increase worker injury potential. Hydraulic, pneumatic and mechanic errors, electrical, electronic and electromechanic parts failure or electrical power disruption, can cause robotic malfunctions. These risks should be considered, and preventive countermeasures applied before integrating robots into the workspace (EU-OSHA, 2022a).

Having a troubleshooting incorporated into the system could be a good practice to help repair smaller issues (EU-OSHA, 2023).

Ergonomy – To keep workers comfortable and prevent fatigue, designers should follow ergonomic design principles. Tools such as Rapid Upper Limb Assessment (RULA), Lower back analysis, Static Strength prediction (SSP), among others, can be employed to evaluate ergonomic design (Raza, 2022). Machinery Regulation requires avoiding machine-determined work rates, prolonged concentration for supervision, demanding working postures or movements, strenuous manual exertion and awkward postures.

Ideally, the equipment should be adjustable to accommodate a diverse workforce, ensuring optimal comfort for operators of varying heights and physiques and sufficient workspace to operate.

Interfaces –To prevent human error, the system must have clear instructions and language and be user-friendly. Good contrast, clear fonts and large text size make it easy to read. The system should alert users to possible distractions or errors. It should also be easy to understand, learn and use. Information and warnings on equipment and its components, should use symbols or pictograms that are easily comprehensible.

Cognitive Load – New solutions design also involves considerations to prevent cognitive underload or overload thereby maintaining job interest, which could prevent work-related stress (EU-OSHA, 2018).

Noise Control – When constructing equipment and end-effectors, attention must be paid to noise levels; materials selection and other noise reduction techniques should be employed (Regulation (EU) 2023/1230 of the European Parliament and of the Council of, 2023).

Effective Lighting – Operation lighting must prevent shadow areas; dazzle and stroboscopic effects on moving parts that might present hazards must be eliminated. Internal parts requiring maintenance or intervention must have appropriate lighting (Regulation (EU) 2023/1230 of the European Parliament and of the Council of, 2023).

Fire Risk – The possibility of overheating or risk of fire originated by products used in the robots such as liquids or gases or the combinations among them and others present on the future workspace, must be assessed (Regulation (EU) 2023/1230 of the European Parliament and of the Council of, 2023).

Cybersecurity measures – New technology should integrate comprehensive cybersecurity measures throughout the system, to protect not only the digital infrastructure, workplaces, production lines and clients, but also the overall system's integrity. Targeted attacks to singular applications from the outside are improbable scenario in AI based systems and advanced robotics because attackers targeting a company would likely attack a larger digital infrastructure (EU-OSHA, 2023). However, when handling data exchange and worker interaction are involved, the need of cybersecurity increases. Ideally, security should be integrated by design, recognizing that AI systems can be both targets and potential tools for cyberattacks (EU-OSHA, 2022b). As technology becomes increasingly interconnected and relies more on distributed communication between systems, cybersecurity is recognized as a contributing factor to physical risk when working with robots. Secure software development practices are essential to prevent external influences that could lead to unsafe machine behavior. Developing preventive measures against common cyber threats, such as viruses, worms, trojans and buffer overflows benefits all the stakeholders (EU-OSHA, 2022a).

Validation and Residual Risks

Prior to robot deployment, a conformance check must verify risks and related safety measures to ensure risks are adequately eliminated or reduced and if the residual risk is at an acceptable level. However, a warning device must be set (Regulation (EU) 2023/1230 of the European Parliament and of the Council of, 2023) and end users must be informed about any residual risks. They should also be informed about any specific training requirements, and which personal protective equipment operators should use, if necessary. Developers should consider not only the intended use of the robots but also anticipate potential misuse.

Certification and Compliance

Acquired components, such as cameras or sensors, should have certification to ensure product compliance with relevant standards (Javed, et al., 2021), along with a handbook providing technical guidance, maintenance guidelines and safety considerations. Robots and systems developed should be evaluated for its compliance with EU regulations and relevant existing standards.

Implementation

OHS Management
The integration of the new robots, end-effectors or other components, into OSH management system should occur early on (EU-OSHA, 2023). The organization must identify, eliminate or control work-related risks to enable swift and efficient issue resolution during or shortly after implementation (ILO, 2001).

Risk reassessment
The intrinsic risks of new equipment and its operation must be assessed and mitigated through preventive measures. While automation may reduce or eliminate recurrent problems, it requires a fresh perspective to identify new risks associated with its implementation. These risks can impact workers, equipment and processes and include mechanical, electrical, chemical, ergonomic, cybersecurity hazards.

Equipment Installation
Equipment and components, including sensors and cameras, should be installed in easily accessible locations to reduce hazards during equipment maintenance and cleaning. Robots must be properly installed, to prevent movement or dislocation parts resulting from possible vibrations during operation (EU-OSHA, 2022a). Layout considerations help to ensure that component movements do not pose a risk of trapping or crushing employees. During robot system implementing, whole-body hazards must be eliminated or controlled. Attention must be given to hazards posed by walls, equipment, or any other rigid and fixed structure present nearby.

Transparency
Maintaining effective communication with workers and their representatives is recommended to reduce workforce resistance to technological implementation. Transparency during the implementation process is essential to avoid mistrust, which could negatively impact on OSH (EU-OSHA, 2023).

Residual Risk
Operators must understand that there will always be a residual risk of injury from unforeseen malfunctions, misuse, or human oversight despite safety measures. Organizations can adopt additional measures such as more safety signs, or invisible barriers that trigger an automated stop if crossed (EU-OSHA, 2023). Other OSH actions include ergonomic studies and organizational measures.

Employee training
Employees should receive proper training specific to the robotic system and the work context in which it will be employed. Whenever possible, employees should undergo reskilling or upskilling, gradually becoming familiar with the new technology in the new work environment (EU-OSHA, 2022a). Effective and timely initial training must be provided to all employees involved in the process, by competent individuals, preferably during working hours. The organization should define OSH competencies required for employees to always perform their roles safely and responsibly. A combination of formal training and hands-on learning may be sufficient. Maintenance operators may require additional training based on their existing competencies, with the amount of training tailored to their prior experience and skills (ILO, 2001).

Operation

Operational Deviations

Deviations detected during operation must be solved promptly during the operational phase. Employees should be encouraged to identify and report issues with the automated system, and organizations should recognize their contributions to incentive proactive engagement.

Documentation and Operational Procedures

Comprehensive documentation and operational procedures should be created for automated systems and revised after any modifications take place. Procedures should be easily accessible at workstations for operator reference. Robots' handbook, available in the native language, must be both stored and readily accessible near the equipment for operator consultation. Even systems with troubleshooting capabilities should have a paper copy available in case of system failure. All documents must be kept up to date.

Continuous Training and Evaluation

Training must be ongoing and include safety and health. Training programs should be modified as necessary to be kept relevant and effective. Operators should undergo evaluations to gauge their knowledge retention from training, with records maintained for follow-up (ILO, 2001).

Recordkeeping

Maintaining records of accidents and investigation results, near-misses, training, system design, operation and maintenance helps to understand the system itself and to proactively act towards continuous improvement.

Cybersecurity Measures

Automated systems should be secured to prevent unauthorized access, use, disclosure, disruption, modification, or destruction. This can be achieved through a layered security approach including strong passwords, encryption, access controls, regular software updates, monitoring for suspicious activities and proper data disposal.

Maintenance

The safety of digitalization/automation tools should be monitored and reviewed. Regular inspections and preventive maintenance help to prevent failures and errors, allowing for the monitoring of processes and early detection of critical issues. Equipment must be totally stationary during adjustments, maintenance, repairs and cleaning.

Fire Hazard

Robotic systems, like most electrical machines, pose a potential fire hazard to the workplace. This can be triggered by overloading the robot, due to electrical overload, or improper electrical installation or maintenance.
Using authentic electronic components during maintenance is important to ensure a continuously safe working environment (EU-OSHA, 2022a).

Continuous Improvement

OSH system should be regularly revised and further improved, in a cyclical manner to continuously enhance employee's safety and well-being.