European Agency for Safety and Health at Work

Smart digital systems for improving worker safety and health: overview of research and practices

Comparative report of case studies

European Agency for Safety and Health at Work

Authors: Paweł Hess, Aleksandra Skoczylas, Joanna Smętek, Ewelina Wołosik, Andrzej Zurawski (Ecorys).

Project management: Annick Starren, Ioannis Anyfantis - European Agency for Safety and Health at Work (EU-OSHA).

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1 Introduction

Smart digital systems and technologies entering EU workplaces are reshaping work environments for workers and employers alike. Innovations in smart wearables, exoskeletons, artificial intelligence (AI), machine learning (ML), internet of things (IoT), virtual and augmented reality (VR and AR), among others, are giving new opportunities for preventing and responding to workplace risks.

As part of EU-OSHA's occupational safety and health (OSH) overview programme (2020-2023)[1], EU-OSHA has examined the challenges and opportunities of smart digital tools and monitoring systems for improving workers' safety and health. These systems, leverage digital technology to collect and analyse data in order to identify and assess risks, prevent and/or minimise harm and promote OSH.[2] EU-OSHA has categorised such systems into two types: proactive (preventive) and reactive, albeit acknowledging the potential overlap between the two.[2] EU-OSHA further provided an overview of the risks and opportunities associated with these systems[2] and explored the workplace resources that could ensure their safe and healthy use.[3]

In order to investigate the practical implementation of smart digital tools and new OSH monitoring systems for improving workers' safety and health[4], EU-OSHA has developed a number of case studies. This set of case studies includes both cases of smart digital systems looked upon at the level of provider/developer and cases of companies deploying/implementing such systems. According to the AI Act a provider is a person or entity that develops an AI system and places it on the market. A deployer is a person or entity that uses an AI system. In this report the roles "developer" and "deployer" will be used as the report is based on cases studies using this terminology.[5] The case studies accordingly investigate aspects related to the development stage and to the implementation stage. OSH aspects including worker's involvement was considered in all case studies taking into account the type of case study. Further, all case studies look at possible drivers, barriers and success factors for safe and effective implementation.

This report presents a comparative perspective on the research conducted under EU-OSHA's 'Overview of research and practices in relation to smart digital systems for improving worker safety and health'.

The objectives of EU-OSHA's overview study included the following:

- to investigate the design, development and deployment in the workplace of smart digital occupational safety and health (OSH) monitoring systems;
- to investigate the impact of the deployment of smart digital OSH systems on workers (positive and negative, opportunities and challenges);
- to identify case examples (potential case studies) and secure access for further fieldwork; and
- to develop a set of case studies.

The study aimed to diversify the case studies in terms of several factors, in particular:

- risks addressed by the solution in focus and OSH results and impacts;
- trigger factors and reasons for deployment, deployment learnings;
- types of technologies used in the system;
- economic and industrial sectors of application;

[1] For more information, see: osha.europa.eu (n.d.) Digitalisation of work https://osha.europa.eu/en/themes/digitalisation-work

[2] EU-OSHA (2023). Smart digital monitoring systems for occupational safety and health: uses and challenges. https://osha.europa.eu/en/publications/smart-digital-monitoring-systems-occupational-safety-and-health-uses-and-challenges

[3] EU-OSHA (2023). Smart digital monitoring systems for occupational safety and health: workplace resources for design implementation and use. https://osha.europa.eu/en/publications/smart-digital-monitoring-systems-occupational-safety-and-health-workplace-resources-design-implementation-and-use

[4] The term 'new OSH monitoring systems' is used interchangeably with 'smart OSH monitoring systems' and 'smart digital systems' for OSH monitoring.

[5] In previous EU-OSHA's publications, the terms "designer", "implementer" and "system user" were used. That is because at the time those publications were prepared (2021), the AI Act (Regulation (EU) 2024/1689) was not adopted by the European Parliament.

- company size, country and region of application; and
- case type — designer/developer or deployer/user of the system.

In total 9 case studies were developed. For each of the case studies, a tailored research protocol was developed in cooperation with the company in focus, to ensure that all relevant information was collected. The data collection methods included desk research, individual interviews with key informants, focus group discussions and contextualisation interviews. At company level, up to five interviews were conducted with operators, data protection officers, health and safety engineers, managers, work councillors and technology officers. The interviews had a duration of 1-1.5 hours each and were performed in the participants' native language, if possible, or alternatively in English., The results of the interviews were anonymised. For the case studies referring to developers, results include limited information from specific implementing companies.

Detailed findings of the case studies are presented separately, in stand-alone case study reports. This report presents a comparative perspective on the collected data, discussing the key findings related to the implementation of new monitoring systems and the impacts they have on OSH. The report also presents recommendations based on the conducted research.

2 Overview of cases included in the study

2.1 Definition of smart digital systems for OSH monitoring

The literature review conducted as part of EU-OSHA's studies on smart digital systems highlighted the lack of a clear, distinct and widely used definition of smart OSH monitoring systems, including at the EU level.[6] EU-OSHA developed the following **definition** of new OSH monitoring systems (or smart digital systems for OSH monitoring) for this study, drawing on existing definitions of OSH and other monitoring systems, and the evidence gathered on their types and purposes: '*New OSH monitoring systems use digital technology to collect and analyse data in order to identify and assess risks, prevent and / or minimise harm, and promote occupational safety and health'*.[7]

2.2 Characteristics of smart digital systems for OSH monitoring

The above definition allows capturing examples of various **technologies** that are incorporated into the monitoring systems to help improve OSH in the contemporary workplace.

Constituting the foundation for the smart OSH monitoring systems covered by the case studies, **widespread connectivity** is a factor that transforms the workplace, operation site or office from a physical to a digital space, which enables an "instant access"-environment.[8] To some degree, all of the systems utilise connection to the Internet — via Wi-Fi or cellular network — to perform their functions. Wearable devices transfer **data to the cloud** for analysis that would otherwise be unavailable because of the limited processing power or impossible to display. Connectivity also allows workers to connect to their workplace via a laptop or smartphone at any time and from any place, reducing barriers and allowing **remote communication and work**.

While such applications significantly rely on high-bandwidth and low latency digital infrastructure for success and efficiency, such infrastructure is becoming increasingly available at households and employment sites. Widespread connectivity, together with the proliferation of **mobile devices** that have portable functionality, such as smartphones, tablets and laptop computers, has played a significant role in the wake of the **COVID-19 pandemic**. Among the cases covered in this study, the most notable example of remote work solutions is "Assisted reality device for remote OSH assessments & audit"

[6] EU-OSHA – European Agency for Safety and Health at Work, *Smart digital monitoring systems for occupational safety and health: uses and challenges*, 2022. https://osha.europa.eu/sites/default/files/Smart-digital-monitoring-systems-uses-challenges_en.pdf

[7] Ibid.

[8] Deloitte. (2014). *The digital workplace: Think, share, do. Transform your employee experience*. https://www.deloitte.com/content/dam/assets-zone2/be/en/docs/industries/technology-media-telecommunications/2023/the-digital-workplace-deloitte.pdf

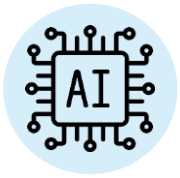
where Assisted Reality (AR) R-devices (such as smart glasses) are used for **remote OSH assessments and audits**.

Apart from remote work, connectivity is also paramount for the functioning of 'smart' OSH monitoring systems, which largely rely on real-time or occasional connection to the Internet. Conceptually, such systems can be viewed as part of the **Internet of things (IoT)** — a term that 'does not simply describe a new type of technical architecture, but a new concept that defines how we interact with the physical world.'[9] The IoT merges physical and virtual worlds, creating smart environments while using three primary technologies: **sensors, networks and analytics**.[10]

In the context of OSH applications, the IoT's primary benefit is that it enables monitoring of the environment and the workers allowing a proactive approach and effective management of OSH. Our case studies provide a wide range of examples of how **advanced sensors** are currently integrated into devices that use wireless technologies (e.g. **Bluetooth or Wi-Fi**) to connect to networks and the Internet. For instance, in "Smart armband for real-time data analysis for health & safety", IoT-enabled sensors on a wearable device transfer data to cloud-based software that serves as a platform for analytics. Similarly, in the system presented in the case study "Preventing hand-arm vibration syndrome", a wearable device provides information on vibration to the worker, but also transfers data to the cloud. Advanced, miniaturised sensors can even monitor brainwaves, as in "Smart headband for fatigue risk-monitoring" solution, or detect trace amounts of gases, as in "Smart sensors for hazardous gases".

IoT-enabled **wearables** such as smartwatches have become widely used in many spheres of life, leading to the phenomenon of a quantified-self, whereby individuals obtain self-sensing or self-monitoring information through wearables and computing.[11] Increasingly, such wearables are also used in workplaces for workforce management and improving the safety and health of workers. Monitoring systems that use wearables can be based on dedicated, industrial devices or off-the-shelf consumer-market devices. Importantly, both types of devices usually provide geolocation information either through GPS or cellular phone connectivity. Such information can significantly reduce reaction time in case of accidents or other OSH-related events.

Data from wearables and IoT devices are usually analysed in real time or available for later analysis on cloud-based platforms. Such analysis is increasingly often conducted by **artificial intelligence (AI) and machine learning (ML)-based systems** — that is, systems that 'can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions.'[12] Their use has gained considerable attention over the past decade as these systems are increasingly capable of processing ever larger quantities of information and of taking over physical and cognitive tasks.



AI and ML have significant potential in OSH applications, especially when compared to traditional ways that involved humans closely monitoring relevant data in order to track working and environmental conditions, as well as events or accidents. AI and ML monitoring solutions have proven to be able to pinpoint issues faster and with better accuracy than humans. In this study, AI technology is implemented in the case of "Event recognition for improved safety management", whose system integrates into video infrastructure to automatically detect and identify safety-compromising events as they occur, and "Wearables to monitor & improve posture – ergonomics", which uses AI technology to measure

[9] Microsoft. (2017). *Cybersecurity policy for the Internet of things*. https://www.microsoft.com/en-us/cybersecurity/content-hub/cybersecurity-policy-for-iot

[10] European Commission. (n.d.). *Europe's Internet of things policy*. https://digital-strategy.ec.europa.eu/en/policies/iot-policy

[11] Lavalliere, M., Arezes, P. M., Burstein, A., & Coughlin, J. F. (2015). *The quantified-self and wearable technologies in the workplace: Implications and challenges for their implementations*. Sho2015: International Symposium on Occupational Safety and Hygiene, 161-163. https://hdl.handle.net/1822/38579

[12] High-Level Expert Group on Artificial Intelligence. (2019). *A definition of AI: Main capabilities and disciplines*. https://digital-strategy.ec.europa.eu/en/library/definition-artificial-intelligence-main-capabilities-and-scientific-disciplines

movements and ergonomic risks in the workplace. During this research, EU-OSHA came across different kinds of AI-based systems, from developers either inside or outside the EU, that can be used in many different applications.

It is worth noting that the cases collected in this study show how **a set of technologies can be combined and integrated to improve the detection, assessment and management of risks for OSH purposes**. In all cases, new technologies are used for specific functions - resulting in integrated, smart systems that fulfil the definition of a new OSH monitoring system.

2.3 Proactive and reactive approach of smart digital OSH systems

There are **two key overarching approaches of new OSH monitoring systems**: a proactive approach that seeks to prevent harm and, more broadly, promote health; and a reactive one that focuses on the response to accidents and emergencies. In particular:

- **Proactive** types facilitate the process of assessing risks preventively by making it quicker, easier, cheaper and at times continuous (i.e. 24/7); they allow safer and tailored interventions as well as 'on-the-job' feedback or support; they seek to prevent harm by detecting workplace (environmental, behavioural) risks early or even predicting them (when AI and ML are used); they measure exposure or exposure responses to different types of hazards to support evidence-based prevention/intervention (e.g. routine checks and maintenance, provision of data for adaptations and adjustments to improve OSH); and they may also support a more positive approach to health and safety promotion in terms of healthy lifestyles and safer/healthier work processes and workplaces.
- **Reactive** types seek to minimise consequences of accidents and emergencies that have already occurred; they improve accident reporting by making it quicker, automatic, cheaper, easier and involving less stigma; they improve accident investigation, by making it safer, more efficient and targeted; and they may also support a more positive approach to health and safety promotion in the workplace in terms of corrective measures to prevent or minimise harm and promote safety in the future.[13]

It should be noted that the types are non-exclusive, and in fact the smart digital OSH monitoring systems covered in the case studies are representative of both approaches.

2.4 Overview of the case studies

The boxes below provide a brief description of each case study. Detailed information can be found in each case study's stand-alone documents.

Preventing hand-arm vibration syndrome	
United Kingdom	Wearables

The company is a Scotland-based SME active in the field of occupational health and safety risk prevention. The company employs approximately 40 workers, and specialises in providing smart digital solutions for hand-arm vibration syndrome (HAVS) through different smart digital systems employing various technologies. Their main system is designed to prevent HAVS by providing workers with real-time information regarding their exposure to HAV, by calculating and displaying workers' exposure.

Depending on the context and the wearable, the company collects data on remote and lone workers' location, slips/trips, fall detection, level of noise entering the ear, level of harmful particulates or level of exposure to vibration. The company's solutions are mostly used in the construction and manufacturing industries and serve proactive purposes to prevent HAVS by identifying when exposure levels are becoming excessive.

[13] EU-OSHA – European Agency for Safety and Health at Work, *Smart digital monitoring systems for occupational safety and health: uses and challenges*, 2022. https://osha.europa.eu/sites/default/files/Smart-digital-monitoring-systems-uses-challenges_en.pdf

Event recognition for improved safety management

Ireland AI / Computer vision

The presented company uses computer vision to develop systems that detect and predict employee safety risks. The enterprise developed an OSH monitoring tool that leverages the power of AI to improve safety reporting in different working environments. By integrating it with the existing closed-circuit television (CCTV) network, the company's technology automatically detects and identifies safety-compromising events as they occur. It then records these events, enabling safety managers to thoroughly analyse and generate reports enriched with data-driven insights. In addition to monitoring and detecting hazards, the company's AI can develop predictive models that help identify potential risks before they occur, allowing employers to take steps to mitigate these risks and prevent accidents from happening. Indeed, the company provides reporting and dashboard functionalities that enable OSH teams to build comprehensive safety audit reports. The monitoring tools are used in various work environments, such as manufacturing facilities, warehouses and ports. This way the deployers are supported to make proactive safety decisions that help contribute to a safer work.

Smart insoles for lone worker protection

France Smart PPE

A French company designs and develops smart insoles for worker protection, especially for lone workers. The insoles are fitted with an integrated electronic module and a wireless charger. In the case of a fall, an integrated sensor detects when the worker is in a non-conventional (i.e. horizontal) position. This triggers a pre-alarm, making the insoles vibrate (on and off). If the worker does not react after 30 seconds, the insole automatically sends an emergency geolocated alert to the employer. The system allows the worker to send alerts to their manager and vice versa, allowing the manager to send alerts to workers and providing a two-way system of communicating emergencies. Alert signals are sent to and processed by a secure cloud platform, which immediately transfers the alert information to the safety manager or supervisors in charge via app notification, SMS or email. Additionally, the company also produces beacons to boost positioning features inside industrial buildings where satellites' coverage may be more challenging. The developer indicated that these systems have been implemented mainly in construction, energy and facility management industries. The smart insoles technology is designed and categorised as reactive, allowing a quicker intervention in case of incidents/accidents.

Smart sensors for hazardous gases

United Kingdom / Germany Smart PPE

The main product of this case study consists of multi-gas detectors, which can be used as part of an infrastructure that connects it to a cloud platform. The multi-gas detector developed is one of the smallest portable multi-gas detectors on the market, which can measure up to six gases using two types of sensors, that is, infrared tech and electrochemical. The portable device displays the values of all atmospheric conditions immediately and sends alerts to workers in case they exceed the threshold limit values. The solution's main use is for personal monitoring and is very useful in confined spaces. The company solution is used in very hazardous work environments such as sewerage, mining, water treatment and catalyst handling. Through the cloud platform, safety and health managers can receive live geolocated measurements from the gas detectors in facilities and manage their fleet, including checking which equipment is ready for use through the cloud platform. This case study's gas detectors are classified as reactive since they allow for a faster and accurate detection of harmful exposure thresholds.

Smart armband for real-time data analysis for health & safety

United States Wearables

This case study presents a system developed by a United States-headquartered company that combines wearables and hardware with special software — a platform that enables effective safety management. Both elements allow to provide immediate access to real-time environment, health and safety data with predictive value. In practice, the wearable device described gathers real-time data on risks and hazards in the workplace. It also monitors environmental risks, such as air quality, sound exposure and air pressure. Then, the software platform displays data analytics, while through the use of AI and ML it can discern trends, and generate alerts and recommendations. To that end, OSH personnel can take proactive steps and implement control measures to improve worker health, safety and productivity. This technology presented in this case study is adapted for workers in manufacturing, construction, transportation and storage services, accommodation and food services.

Wearables to monitor & improve posture – ergonomics

United Kingdom Wearables / Data analytics

The case study presented is developed by a company located in the United Kingdom that operates globally. The company developed two main systems, consisting of a wearable solution for injury prevention and a cloud-based solution. The wearable device uses AI to coach workers to self-correct their movements and postures in real time to avoid injuries. As for the cloud-based solution, this combines video captured through the company's mobile application with AI-driven data analysis to measure risk movements in the workplace. Concerning the OSH aspect, workers can instantly access data on their movements and postures, which allows them to visualise their working day. Collected data enable workers to detect dangerous positions during a specific shift, see the exact time spent on back twisting and track which time of the day they are the most subject to hazardous movements. Such systems are used in various sectors, including warehousing, retail, logistics and manufacturing, focusing on activities that involve a high level of hazardous and repetitive movements. This OSH monitoring system is proactive with its main goal to be accident prevention.

Smart headband for fatigue risk-monitoring

Canada / Australia Wearables

This case study presents a wearable device that continuously monitors user's fatigue level. The fatigue level is monitored through electroencephalogram (EEG) signals, analysing frequency data to determine the user's fatigue or alertness level. These data are transmitted to a mobile app, which, in turn, uploads them to a cloud platform. The user can receive immediate alerts and feedback on their smartphone or other devices. Regarding OSH, the solution's added value lies in the fact that it is designed to provide a proactive approach to fatigue. The product is used in various sectors but is particularly effective for activities where fatigue can cause major incidents/accidents, that is, drivers or vehicle operators on construction sites. The technology measures fatigue and vigilance in real time allowing early detection and effective measures to be taken.

An OSH smart control centre
Spain / Worldwide Big data
A Spanish company operates globally in over 40 countries. They developed an internal system for advanced safety management of remote sites. The system records all information on OSH, such as inspections, audits, incidents and external factors that impact risks at a workplace through a control centre, which allows 1) data collection, 2) data analysis, 3) data display and 4) responding to data insights. The system allows safety professionals to monitor and manage events at different remote sites (workplaces) simultaneously and plan their activities, such as inspections or interventions, accordingly. In that way, the system operates in a proactive way since it helps in accident prevention but also reactively as it sends signals and notifications when a reaction is required. Since 2023, the system is a standard tool used company-wide for management and accident prevention.

Assisted reality device for remote OSH assessments & audit
Germany / Worldwide Smart PPE / Wearables
The company which developed the system presented in this case study is a global conglomerate specialising in industries of health, energy and construction. The system consists of smart-glass-type devices for purposes of conducting remote OSH assessments and audits. Such assessments employ digital technologies to allow OSH professionals, experts and auditors to participate in events remotely, in real time, eliminating the need for physical presence on site. The device can be optionally mounted on safety helmets and bump caps and used with hearing protection, safety glasses or corrective eyewear. Thanks to this device, workers can access information, assistance and expertise while keeping their hands free. This is a significant advantage in terms of usability and contributes to workers' safety. This system is mostly used in big manufacturing and construction sites, while it is both proactive and reactive.

3 Implementation process

3.1 Motivators and goals of system implementation

The conducted case studies highlight two perspectives on the motivators and goals of new monitoring system implementation: that of the system developers, and that of the companies in which these systems are implemented and deployed. For **system developer companies**, the motivation lies in **offering innovative OSH technologies, while running their business activity**. However, in many of the cases, developers' motivations **included developing 'solutions' to address preventable risks** or unleashing technology's potential to support health and safety in the workplace. For example, the technology development described in "Event recognition for improved safety management" was triggered by exposure to a fatal workplace accident that could have been avoided by putting preventive measures in place, while an interviewee in "Wearables to monitor & improve posture – ergonomics" pointed out the high number of work-related accidents and the general lack of digitalisation of OSH departments in companies as forces driving technology development.

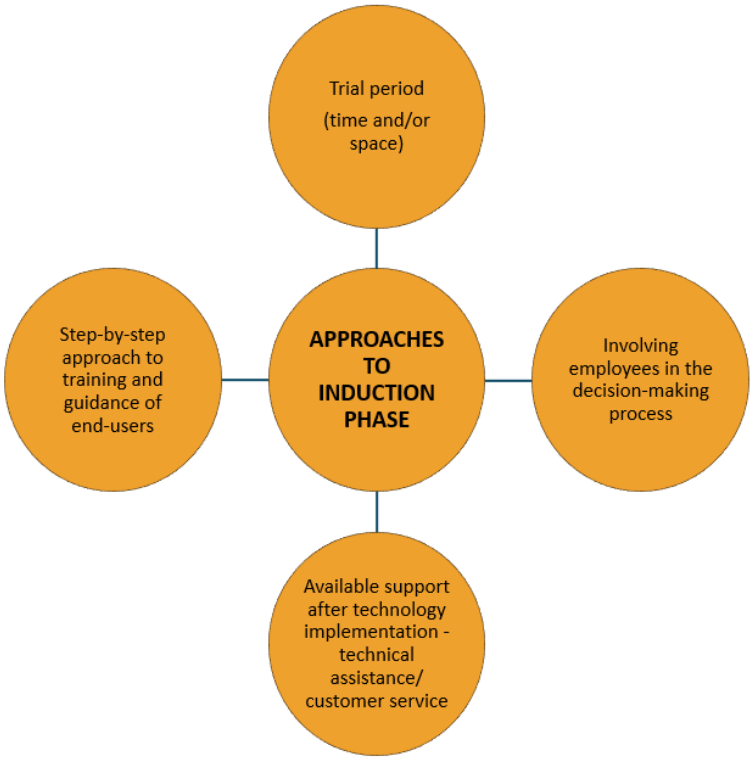
Considering the motivation of the companies in which the systems are implemented, **the system deployer companies**, some mentioned 'traditional' motivation related to **legal compliance**. Indeed, as presented in the case study "Smart sensors for hazardous gases" and case study "Wearables to monitor & improve posture - ergonomics", the ability was mentioned to address regulatory requirements while having some additional insight gained via monitoring technologies. NB the employers of the deployer companies will often be the responsible employers for the workers affected as end-users of the systems. Other examples of deployers' motivations indicate the need to address some issues that, in their perception, required **additional, non-conventional solutions**. In the case study "Smart insoles for lone worker protection", the employer faced increasing reports of elevated stress, isolation and fatigue levels among workers and was aware of limited-effect traditional solutions, which were non-compatible with

workers working remotely. Other leads suggest that **some forms of external pressure, urgency or complexity** of company operations can motivate to look for OSH technologies, as in the examples of the case study “Event recognition for improved safety management”. One of their clients (deployers) mentioned how they struggled to maintain safety due to the complexity of activities and personnel; another witnessed a heavy increase in customer orders during the COVID-19 pandemic, increased workforce and faced challenges to secure safety in the new environment. Indeed, another client noticed that when companies are experiencing high volumes of incidents and incident-induced sickness absence, management is usually keener to take appropriate measures to resolve OSH-related issues.

Introducing new technology into a company and workforce was often an elaborate and multi-step process, including various forms of worker involvement. **Companies need time to familiarise themselves with a given technology**, understand its functions and limitations, and properly understand how it can be used for company purposes. Equally, companies need time and *support to introduce technology to their workers, properly train staff, and address any concerns or issues before full implementation*. Indeed, interviewees considered end-users’ proper *understanding* of a given technology and its *functioning* as an indispensable success factor in technology implementation. Recognising the importance of this factor, they implement procedures that facilitate technology absorption, including piloting, testing and training. In the case study “Wearables to monitor & improve posture – ergonomics”, end-users are introduced to the technology through a two-week pilot phase, which includes testing the technology in a real-life yet controlled work environment. During the testing period, workers can pose questions to the, and all of the issues are discussed and solved before proper technology deployment. In the practice of the case study “Smart sensors for hazardous gases”, workers, as end-users within the implementing company (the employer) are involved early at the developing stage of decision-making as to the specific components to be included in the system described. The implementation process in this case study is similar for each client. The first step is a *site risk assessment*, which determines the types of gases present on site and the required safety measure. Based on the risk assessment results, the workers at site are consulted before selecting a gas detector for a specific application. Later, they receive *training* from the chosen product manufacturer to carry out essential operations on the gas detectors. The case study “Event recognition for improved safety management” also provides a four to five weeks-long *onboarding process*, during which developer’s staff supports and guides the deployer’s IT and surveillance teams in successfully integrating the new system. Equally, the developer presented in the case study “Preventing hand-arm vibration syndrome” provides several *training opportunities to the deployer (employer) on how to set up the system and interpret the data*. Deployer companies can also launch a trial in one site before implementing the solution in each location.

Further, in the case study “Smart headband for fatigue risk-monitoring”, it is evident that building **trust and understanding of what technology does and what it does not is key to the implementation process**. The company developed a comprehensive step-by-step approach to familiarise all end-users (deployers) with the technology within the range of activities, such as discussions, workshops and so on. In the case study “Smart headband for fatigue risk-monitoring” the **representative stressed the crucial role of having the right (implementation) process, even if it is elaborate**. The developing company’s experience is a case against ‘cutting corners’ in this respect, with representative recalling situations when attempts to simplify or shorten the process led to a project implementation failure.

Figure 1: Identified approaches to the induction process



Persons who can be **'ambassadors'** — senior workers, management or respected workers — have an important role to play in the introduction process, as evidenced also by the case study "Smart headband for fatigue risk-monitoring". While all end-users receive training and introduction to the new system and its use, the developer of the "Smart headband" provides additional targeted training to the chosen staff members of the implementing company, the deployer as employer. The chose staff members can also guide their colleagues, run regular feedback sessions before and after shifts, and identify any occurring challenges. Similarly, in the case study "Smart armband for real-time data analysis for health & safety", interviewees stressed the importance as employer that of senior staff 'being the example' by using the technology and encouraging others to follow suit; the process focuses on **providing information and training to OSH specialists, who later guide the rest of the deployers' workers as end-users.**

While not in each company's case, technology introduction was an elaborate process; it included among others to **ensure that end-users have a solid understanding of technology functioning**. In the case of "Smart insoles for lone worker protection" a pilot stage is offered to familiarise end-users with the insole, equally in other cases, end-users were given the brochure explaining objectives, the monitoring process and the preservation of privacy. This was followed by ensuring that each crew member consented to participation. As presented in Figure 1, the study identified four main strategies in the induction phase, consisting of a trial period, including workers in the decision-making process, dedicating the separate step-by-step approach and dedicating technical assistance/customer service staff to support end-users. In many cases, these elements were combined; for example, the developer offers a step-by-step induction process and offers support via technical assistance or customer services to the deployers (employers) after the completed induction process.

3.2 Drivers of system implementation

Our findings from qualitative analysis demonstrate that the **primary driver for implementing smart digital OSH monitoring systems is the desire to increase health and safety in the workplace**. Improved health and safety in a workplace can bring other benefits beyond health too, associated with production and profit. In fact, the majority of studied companies explained that their customers noted increased **productivity and efficiency not solely in OSH-related issues but also in other operations**. Indeed, data collected by OSH monitoring systems allow customers to resolve OSH-

related matters but also allow for better outcomes regarding the company's other operations (e.g. in the logistics departments). As indicated by the interviewed representatives of developers, their customers (i.e. deployers) also reported **reduced employee turnover and worker compensation costs**, which enabled the company to save money and, thus, achieve better financial results and growth. Moreover, several studied companies reported that technologies can have an impact and be effective outside of the work context too. They reported that **workers who are making use of such systems in their work environment are changing their behaviour in the long term and applying their OSH knowledge in personal settings** too (e.g. while gardening or lifting heavy items).

The listed drivers and opportunities related to the smart digital systems as well showed to increase **trade unions' and workers' pressure for ergonomic and innovative OSH solutions to improve and redesign the workplace.** In Europe, where workers' unions and workers are determined and engaged in ensuring safe working conditions, there is a **growing demand to implement ergonomic and innovative OSH measures**. At the same time, the important role of the employers' responsibility to protect workers' health and safety is acknowledged. Increasing OSH regulations and policies across countries have come into place that oblige employers to take concrete actions towards OSH in their workplaces, also at national or sectoral level. To meet these requirements and demands and facilitate implementation, developers of smart OSH monitoring systems need to provide **flexible and adaptable measures** for different contexts. In fact, most of the studied systems can be deployed in various industries ranging from logistics and retail to manufacturing and warehousing and in various structures, that is, from start-ups employing very few workers to global corporations with upwards of 1,000 workers. The aforementioned advanced level of system customisation makes the systems more attractive and suitable to a wider range of uses and deployments, which is also a driver for OSH monitoring system developers.

The COVID-19 crisis was also considered as a driver for implementation that certain companies have seized. In fact, the pandemic has led to a **rise in the use of OSH monitoring systems and a rise in interest in OSH topics in general**. Companies and employers that had not undertaken OSH measures (e.g. risk assessments) started to show interest in them, especially in ways of proceeding with OSH digitally, as face-to-face interactions were limited. For some of the studied companies, the increase in deployed OSH monitoring systems, materialised in increased activities and revenues. One of the cases (Smart armband for real-time data analysis for health & safety), decided to provide a worker density mapping feature that enables one to view the density of workers by facility location or site area over time. This feature helps to ensure social distancing or to implement adequate sanitary measures if needed. Since the wearable has an integrated unique identifier system, it can detect with whom a worker has been in close contact. For "Wearables to monitor & improve posture – ergonomics", the COVID-19 pandemic was also an impulse to develop a tracking feature to track on-site proximity between workers. However, this idea did not materialise because the company decided to focus on its core business, that is, prevention of injuries.

The last driver is linked to **technology proliferation** among companies and in workers' daily lives. In fact, when the technology in question becomes an integral part of workers' lives, when workers are familiar with it (e.g. smartphones or computers) and see the benefits of deploying such technology in a work context. They start pushing for an integration of such tools in the workplace or at least remain less reluctant to use such technologies.

3.3 Barriers to system implementation

Even though the adoption of smart digital OSH monitoring systems is designed to protect workers, promote OSH and thus benefit organisations, these systems also face obstacles. The paragraphs below describe the most common barriers that arise during the development and deployment processes.

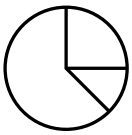
The most recurrent barrier concerns **data privacy**. The intensity of related concerns differs depending on countries' national regulations/laws. Given the provisions defined by GDPR, EU Member States apply more strict data protection policies, when compared to other parts of the globe, as noted by global companies developing cases. Differences in legislative contexts mean that companies designing OSH monitoring systems have to adjust accordingly, which could slow down development and, in some cases,

this customization could lead to hindrances in the development and/or implementation of the OSH system.

Data confidentiality concerns could come from workers who are reluctant to adopt data-collection technologies because of the **possible data misuse**. In fact, although the primary purpose of these technologies is to gather data in order to ensure/improve workers' health and safety, additional measures and strict policies are needed, especially when these technologies are also able to collect biometric and other sensitive data. Moreover, workers are concerned that these solutions will track them on a regular basis **by collecting productivity/performance indicators**. Employers must draw a clear line and articulate the purpose of the implemented solution — do smart monitoring systems collect data on performance or OSH, or both?

To dispel the data protection concerns mentioned above, designing companies encourage their clients to educate workers about the General Data Protection Regulation (GDPR) and other data privacy-related procedures. For instance, during the testing phase of its solution, the developer in the case study "Smart insoles for lone worker protection" organises **special data privacy and confidentiality training** sessions to discuss and raise workers' awareness on these issues. Sessions are designed so as to explain to workers the aim of the system and to whom and to which extent collected data will be accessible. Finally, the developing company decided **to 'activate' the geolocation data feature solely when an alert is triggered**. **Workers themselves also have access to collected data** and can see what data their employers can view. Similarly, another company decided to **collect data related strictly to the number of hazardous movements** and restrained itself from tracking workers' location and productivity indicators.

Another potential remedy for this problem could be found in the **full anonymisation of data** — a practice adopted by "Wearables to monitor & improve posture – ergonomics". The anonymisation of data admittedly ensures the protection of workers' privacy. At the same time, **it may alter the results of the implementation and use** of the smart OSH monitoring system, that is, the system will not be used to its full potential to improve OSH in its workplace.



The second most cited barrier by studied companies lies in the **lack of maturity of certain sectors/markets/industries** to implement these types of solutions. In fact, several surveyed companies mentioned that they have to deploy considerable resources, that is, time, human and financial resources, to **raise potential implementing clients (deployers)' awareness** about the technology they are designing/implementing. This issue particularly affects companies *developing cutting-edge technologies, which are still niche and rarely used on the market*. Especially related to those cases making use of AI technology and/or work with personal data, companies still continue to put significant efforts into educating audiences on the uses of the system, to build trust and understanding. Awareness-raising activities require upstream work, which may slow down the implementation process. However, once this upstream work is completed, end-users have a better understanding of the system and, thus, are more engaged with it. A key element in engaging end-users, i.e. employers and workers, **is clear and transparent communication on the purpose and use of the system**. Indeed, representatives of companies included in the study have agreed that when workers know that the technology's main purpose is about ensuring their health and safety in the workplace, they are keener on adopting it and are more positive about incorporating it into their daily activities.

The lack of maturity mentioned in the paragraph above can be associated with certain companies' **resistance to implementing high-tech solutions**. In fact, the collected evidence suggests that some companies are reluctant to use wearables, AI and other cutting-edge technologies in their workplace. The reluctance could be a result of **misconception and poor knowledge about these technologies**. In addition, some employers perceive the smart digital OSH systems as non-returning investment or long-term investment that is strategically not worth making given the associated cost. Another

reason behind the hesitance to adopt high-tech solutions is workers' and high-management representatives' **perception of new technologies as a replacement for actual workers**. As explained by the Account Manager in the case study "Wearables to monitor & improve posture – ergonomics", 'there is still a long way to go and effort to make in explaining that the technology is not there to replace humans but help them'.

In certain cases, the **reluctance mentioned above could be linked with indifference**. In fact, in one of the studied cases, it was noted that even if accidents in workplaces are a frequent occurrence, some employers do not take the necessary actions to resolve problems — problems are put aside. Lack of action in this regard also leads to worker disengagement from OSH issues. In this line, low absorption of OSH technologies is related to the low status of OSH itself on the agenda of employer's management. To counter this disinterest, OSH institutions at local and regional levels could organise more OSH awareness-raising events among workers and companies, explaining the importance of OSH and the implications of overlooking this issue.

The third barrier to OSH implementation relates to the **lack of digital skills among** workers and inadequate ICT infrastructure — especially in SMEs — to implement smart digital OSH systems. A number of studied companies reported that their clients, the deployers, experience difficulties in switching from 'paper practices' to digital processes, mostly due to the high costs of purchasing high-tech solutions and the lack of digital skills needed to implement them. As mentioned above, these issues mainly affect **SMEs**. As a result, the adoption rate of high-tech solutions is far lower within SMEs than in large companies.

Concerning the functionality of smart digital systems for OSH, a number of developers mentioned **technical difficulties** that deployers experienced when setting up the systems, which often consist of a large amount of hardware. In the case of one company, workers had problems setting up devices and downloading a specific application.

Additionally, at the beginning of the implementation, some workers (end-users) did not fully understand how to handle the notifications and other functionalities of the system. This lack of understanding could lead to lower functioning, and even lower reliability of the OSH management system. After **training sessions and personalised tutorials**, technical issues were resolved. It was stated by certain developers that tailoring of the software was complex and time-consuming, but important to meet clients' requirements, needs and expectations.

Several developing companies raised concerns about the **accuracy and utility of OSH systems and collected data**. In fact, **overreliance on data** that might not be correctly interpreted could lead to wrong conclusions. For instance, an interviewee in the case study "Wearables to monitor & improve posture – ergonomics" stated that indeed it is complex — nearly impossible — to accurately measure each body movement with only one wearable. This non-accuracy of tools makes it harder to establish whether the data analysis and interpretation processes are rigorous. Another issue relates to workers manipulating their own data since the smart digital system can be bypassed or jammed. For example, taxi drivers could disable seat belt monitoring, or factory workers could take medicaments to lower their temperature during the COVID-19 pandemic or another transmittable disease to continue working. It is therefore important to ensure that accuracy and utility of collected data are of high quality, as they can also be manipulated and should be treated with caution. This issue should be carefully considered when it comes to **AI decision-making.**

Considering the scalability of OSH technologies, **a crucially important factor is investment in time and costs**. Even though those technologies are **expected to reduce the costs of OSH systems in the long run**, some of them may require significant investments at the beginning. Some of those investments are indirect: virtually all the solutions require a permanent Internet connection for sites such as mines or farms that may require significant hardware investments, as pointed out by interviewees of the developer in the case study "Assisted reality device for remote OSH assessments & audit". Furthermore, all the solutions require advanced **staff training**, which is also a considerable cost at an early stage of development. In SMEs, the unit cost of such technologies — particularly those involving mass data processing — is significantly higher than in large companies. Consequently, **SMEs are less likely to invest in those technologies**, and most identified cases for the studies included developers and deployers operating in developed countries. Notably, the investment challenge may not be present

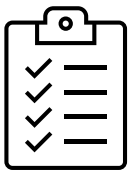
in all technologies or all cases, for example, when there is already a good internet connection in the company or when adapting off-the-shelf or existing items.

The findings are in line with previous research. For example, data collected within the Third European Survey of Enterprises on New and Emerging Risks (ESENER 2019) showed that large companies reported having more frequent discussions about OSH-related issues (67%) compared to micro firms (13%), suggesting that the **perception of OSH's importance depends on the enterprise size**. Similarly, ESENER 2019 illustrates the relatively **low adoption of cutting-edge technologies** in workplaces. In fact, the survey displays the difference between the adoption of 'basic' technologies, such as computers and other electronic devices, and more recent, cutting-edge technologies, such as robots and wearable devices. Overall, the so-called basic technologies such as computers, laptops, tablets and smartphones are widely used throughout all sectors, but the more cutting-edge the technology, the lower its adoption rate. Indeed, the average adoption rate for basic technologies (computers, tablets, laptops, etc.) ranges between 85% and 90%, whereas the average adoption rate for high-tech solutions (robots, wearables, etc.) ranges between 5% and 8%. **Differences in adoption are also to be noted at the sectoral level.** For example, the manufacturing industry had the highest percentage (9%) of using robots that interact with workers compared to arts, entertainment and recreation, as well as public administration and defence, which registered the lowest percentage (1%).

The findings exemplify the issues listed above. In fact, in many studied cases, the developers have agreed that **before adopting cutting-edge technologies**, **deployers need time to reflect, analyse and consult potential adoption with workers.** The more widespread the technology becomes, the more inclined companies are to embrace it. Plus, the studied companies also articulated differences in adoption depending on the sector in question. Globally, sectors where workers are more exposed to accidents and repetitive movements, such as **manufacturing and logistics**, are more inclined to opt for smart systems for OSH.

3.4 Implementation as a cooperative process

In most of the studied cases, the cooperation between companies that develop OSH systems and companies that deploy and use them **is most evident during the on-site deployment** of the system. Regarding the designer–deployer cooperation at the earlier design, development and deployment phase, this is less visible, and if it is often in a form of investment and commitment in keeping with the business model of the developer. In fact, the majority of studied developers began as start-ups in need of financing from different stakeholders, including their potential clients, i.e. deployers. One of the developers, the one presented in the case study "Wearables to monitor & improve posture – ergonomics", started as a start-up, and its CEO explained that achieving the company's concept was possible only with the help of companies (future customers) that have adhered to the company's vision and were willing to pay for it.



As mentioned earlier, developer–deployer cooperation is most evident during the on-site early implementation of the solution. This cooperation is generally composed of key steps that are similar for companies:

- tailoring of the system to the needs of the deployer's needs (OSH and IT representatives, managers and workers), and
- trial and training opportunities (OSH and IT representatives, managers and workers).

One of the crucial phases remains the **testing and tailoring of the system to the end users: the workers of the company deploying the system.** The tailoring and testing stages require regular, clear and transparent communication between the developer and deployer to ensure a common understanding of the objectives to be achieved. The deployer (often: the customer) expresses their expectations and requirements as an employer while the developer tries to adapt and tailor the system to meet the expectations. Since communication is a critical factor at these stages, certain enterprises have decided to develop specific action protocols to render this process smoother. For instance, in the case study "Smart headband for fatigue risk-monitoring" a step-by-step framework of cooperation was established that entailed a detailed plan for the implementation of their smart PPE product. The strategy established communication with the deploying company at all organisational levels, ranging from high

management to end-users and workers. This includes **consulting, briefing, educating and individual consultations with workers.** Some studied companies invited **OSH representatives** to engage in discussions on the optimal way to develop and implement their technologies; however, this was not a common practice.

In the same vein, developers of the case studies “Preventing hand-arm vibration syndrome” and “Wearables to monitor & improve posture – ergonomics” provide specific **training opportunities on how to set up their technologies and interpret data**. During this training, end-users of the deploying company (employers and workers) can ask questions about the smart system and raise any concerns they may have. Both developers also propose a trial in one site before rolling it out across all their sites. This testing period usually lasts around one or two weeks as trial opportunities are an important element for the implementing companies. After the testing phase, if no problems are reported and workers’ concerns are addressed, the system can be deployed throughout the deployer’s worksites.

Some case representatives have reported **complex collaboration with end-users during the design and implementation phase**. In fact, workers are not always keen to spend additional time on testing the new systems, especially when testing means that workers must devote additional time for this and have less time to complete their work duties. It is important that there is time reserved for testing and worker consultation during workers’ regular working hours or that workers’ workload during the test period is reduced.

To summarise, **close interaction between the developer and deployer** and **a common understanding of the needs and priorities** are vital to guarantee the successful implementation of the smart digital OSH systems. System developers and users have to address needs at three levels, that is, at the company level (employer), at the OSH professional level and at worker level. In fact, these three groups have slightly different needs and priorities regarding OSH systems. At **the company level**, objectives are to improve labour standards and safety within the workplace, reduce workplace accidents, increase worker effectiveness and mitigate accident-related expenses. Concerning **OSH professionals**, their needs relate to having accurate and real-time data/indicators on workers’ health and safety (e.g. fatigue level, postures, etc.) and the possibility of locating workers in case of danger. This information allows OSH professionals to make better and more targeted OSH-related decisions. As for the **deployer’s workers and end-users**, their needs are associated with greater safety in the workplace and improved health and wellbeing. If developers and deployers aim for a successful implementation, they need to consider the needs and priorities of the three aforementioned groups and establish cooperation based on regular exchanges, enabling developers to identify users’ expectations more accurately. Such close cooperation was noted, especially in the case studies “Event recognition for improved safety management”, “Smart armband for real-time data analysis for health & safety”, “Wearables to monitor & improve posture – ergonomics”, “Smart headband for fatigue risk-monitoring” and “Assisted reality device for remote OSH assessments & audit”.

4 OSH impacts

4.1 Opportunities

4.1.1 Opportunities for OSH

Overall, the implementation and deployment of the discussed technologies results in identified OSH impacts relevant to the functioning of the smart digital OSH monitoring systems, as presented below.

Figure 2: A comparative perspective on OSH impacts

Avoiding (fatal) collisions with other moving vehicles (truck, car, plane, excavator, ship, bus, train, etc.), resulting in no one being injured.

(Case studies: “Smart headband for fatigue risk-monitoring”, “An OSH smart control centre”, “Smart headband for fatigue risk-monitoring”).

Avoiding accidents (or catastrophes) caused by **external factors,** overexertion, or mental factors.

(All case studies).

Capturing and responding to **near misses** such as slips, trips and falls, improving workers’ ergonomic safety and minimising ergonomic risks.

(Case studies: “Smart armband for real-time data analysis for health & safety”, “Event recognition for improved safety management”, “Wearables to monitor & improve posture – ergonomics”, “Preventing hand-arm vibration syndrome”).

Avoiding exposure to flammable, toxic and asphyxiant gases.

(Case study: “Smart sensors for hazardous gases”).

Avoiding immediate dangers, such as fire and providing direct support.

(Case study: “Smart insoles for lone worker protection”).

Identifying risks in the work environment, such as excessive heat, inadequate lighting or noise-induced hearing injuries.

(Case studies: “Smart armband for real-time data analysis for health & safety”, “Event recognition for improved safety management”, “Preventing hand-arm vibration syndrome”, “An OSH smart control centre”).

The most evident impact of the digital technologies coming from the OSH monitoring systems is **the proactive prevention or avoidance of accidents, collisions, falls and any event that may put workers or any other parties in immediate danger**, often through providing real-time monitoring and immediate alerts. For example, in the case of the CCTV camera-based technology presented in the case study “Event recognition for improved safety management”, one of the deployers, a shipping company, used the solution to identify potential safety hazards. The system detected some possible risks related to the crane operations, workers involved in these operations and pedestrians near these activities. It alerted the company safety team immediately, allowing them to take action before an accident occurred and put corrective measures in place. The technology used in the case study “Smart headband for fatigue risk-monitoring” monitors levels of fatigue to decrease the risks of fatigue-induced or stress-induced events putting workers in immediate danger. Evidence gathered in case study “Smart headband for fatigue risk-monitoring” indicates results in minimising vehicle-related incidents in the sectors relying on human traffic control (maritime, aviation, railway and over-the-road transport).

Other reported OSH impacts confirm the **preventive function of innovative technologies regarding a wide range of OSH risks**. In the case study “Wearables to monitor & improve posture – ergonomics” employers reported a 30-70% reduction in risks and work-related injuries. Similarly, in the case study “Event recognition for improved safety management”, an employer mentioned that the system use resulted in a 40% decrease in unsafe events and an 80% reduction in incidents over a period of three months. In the case study “Smart headband for fatigue risk-monitoring”, it was reported by an end user

in the transportation sector that after 3.5 years and 1.1 million hours of system operation , they had zero fatigue incidents and a 68% reduction in the fatigue alarm rate. Early warning alerts have resulted in 97.7% effective operator self-management actions.

Smart OSH monitoring technologies, **in particular AI/ML**, may have predictive functions, which greatly strengthen the proactive approach to OSH risks. Consequently, adopting such technologies would not **only allow to develop proactive measures or act in immediate danger but also allow to detect any aspects suggesting that a certain risk is yet to happen**. For example, in the case study "An OSH smart control centre", a company developed and implemented a large-scale database technology, allowing real-time monitoring of the company's operations at premises all over the world. A database is used to collect and store traditional and alternative data on workplace safety, from both internal, such as OSH reports, data from CCTV or reports from inspection, and external sources (called smart sources), such as weather reports or information on suppliers and subcontractors. Furthermore, the company is currently working — in cooperation with universities — on a mathematical model feature that will automatically analyse exabytes of data in order to generate early signals on risks or opportunities for a company. Even at an early implementation stage, the model could allow identification of potential risk factors, such as workers not wearing safety helmets.

Finally, **OSH technologies facilitate timely reactions to any events that could not be predicted by any monitoring** tool. Large monitoring systems, such as those presented in in the case studies "Event recognition for improved safety management" and "An OSH smart control centre", supported with CCTV cameras can automatically and immediately detect any unusual situation that may suggest an incident much faster than any traditional alarm. Several wearables can provide even more deep signals, impossible to be seen or detected by usual cameras, either automatically or manually operated. In the case of the smart insole technology described in the case study "Smart insoles for lone worker protection", when the incident occurs, an integrated sensor detects when the worker is in a non-conventional situation, triggering a pre-alarm, which begins to make the insoles vibrate (on and off). If the worker does not react after 30 seconds, the insole automatically sends an emergency geolocated alert to the employer.

From the **system point of view**, adaptation of innovative OSH technologies has strengthened accident prevention by **enabling generation of very specific insights on risks related to the workplace and workers** — enhancing data collection and analysis. There are two ways in which smart OSH monitoring technologies help to improve knowledge: a) by allowing for a **better use of existing data**, or b) by facilitating the collection of **data that have not been gathered by a company before**. For example, in "An OSH smart control centre", designers make use of data that are collected by companies anyway, such as recordings from CCTV systems, reports to state inspectorates, reports from OSH specialists and so on. Thanks to innovative technologies, particularly ML and AI, the implemented solutions allow deployers to analyse much broader datasets and identify risks significantly earlier than traditional methods. At the same time, these solutions also offer a huge variety of new sensors, often wearables, allowing for a multidimensional workplace monitoring.

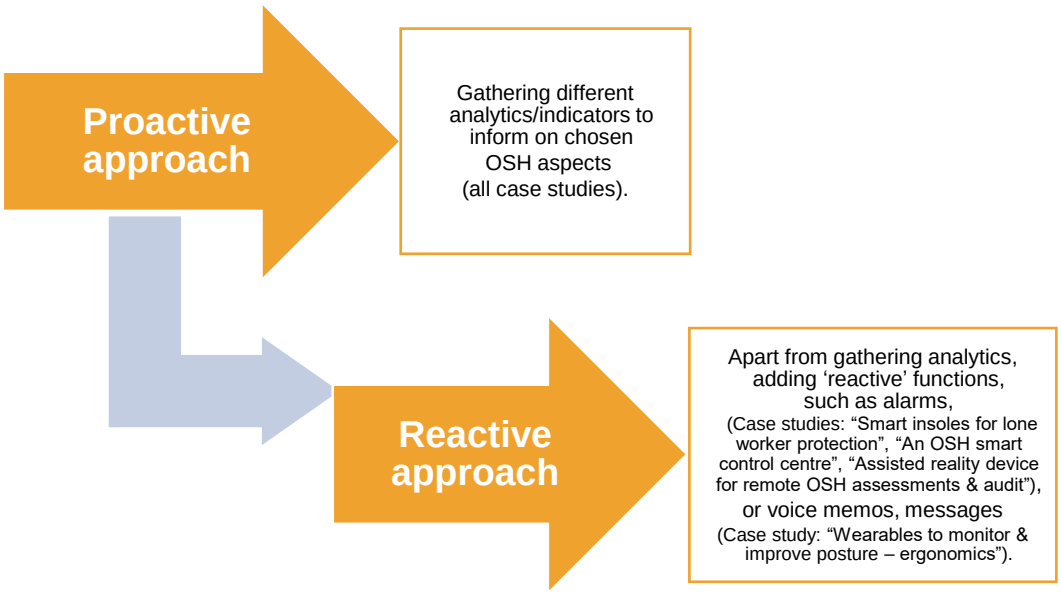
Offering a **significant improvement on traditional sources of data**, the available wearables help to collect data on an individual level and monitor the risk exposure of a single worker. That kind of data helps prevent a broader range of occupational risks than traditional working environment monitoring, allowing for *knowledge-informed decision-making* based on indicators specific to a chosen risk. For example, the solution of "Smart sensors for hazardous gases" aims to combat risks from an exposure to poisonous gases, whereas the one presented in the case study "Preventing hand-arm vibration syndrome" protects workers from injuries related to vibrations. Data-driven insights can lead to better workplace design, improved ergonomics, enhanced training programmes and better resource allocation. The *aggregated data from multiple sources* provide a comprehensive view of workplace safety, facilitating *informed decision-making and trend analysis*.

Furthermore, the technologies and systems described show a **significant broadening in the understanding of OSH**. Instead of focusing purely on accident prevention, designers move towards a much **broader category of workers' wellbeing**. In principle, some of the technologies do not only investigate if the worker is exposed to certain OSH risks such as vibration ("Preventing hand-arm vibration syndrome") and exposure to dangerous substances ("Smart sensors for hazardous gases") but also consider broader aspects such , workers' ergonomic safety ("Wearables to monitor & improve posture – ergonomics"), the comfort of work (CS3) and risks associated with fatigue ("Smart headband

for fatigue risk-monitoring"). Thanks to such solutions, workplaces may benefit not only from increased safety but also from increased job satisfaction or better work efficiency.

Notably, case studies indicate that **the line between reactive and proactive OSH technologies is very fluid**, as indicated in Figure 3. For example, in the case study "Smart insoles for lone worker protection", the technology is clearly aimed at the mitigation of incidents (reactive); the smart insoles technology is designed for lone workers and for monitoring their behaviour in the case of immediate danger encountered. In other cases, the division between reactive and proactive functions is not apparent. Most of the technologies studied have important proactive features, such as informing end-users on the ergonomics ("An OSH smart control centre"), a level of fatigue ("Smart headband for fatigue risk-monitoring"), and vibrations ("Preventing hand-arm vibration syndrome"). However, in many studied cases, adding a function that allows sending alarms or communication could enhance the technology's potential to be both reactive and proactive, as is the case in "Smart insoles for lone worker protection", "Smart headband for fatigue risk-monitoring", "An OSH smart control centre" and "Smart armband for real-time data analysis for health & safety". However, **explicitly combining the proactive and reactive functions may not always be desired by the developers due to potential associated liability**. In "An OSH smart control centre", even though the technology allows workers to leave voice memos for their supervisors, developer's representatives said explicitly that their technology should not be regarded as reactive, since they do not want their end-users to rely on their technology for immediate threats and life-and-death situations, considering legal and financial obligations attached to the technology seen as focused on the response to accidents and emergencies. Indeed, in case the technology would be considered as reactive, the company could face legal and financial consequences when the technology would fail in a life-and-death situation or any major accident in the workplace.

Figure 3: Relationship between reactive and proactive technologies



4.1.2 Opportunities for OSH management

OSH professionals, especially in-house OSH specialists in deploying companies, are direct beneficiaries of the smart digital OSH systems. When fully implemented, various features of the systems, particularly remote features and use of AI, help them **save time and make effective use of resources for managing OSH systems**. An obvious example is *remote assessments and inspections*: several technologies ("Assisted reality device for remote OSH assessments & audit", "Wearables to monitor & improve posture – ergonomics", "Smart armband for real-time data analysis for health & safety") create the opportunity to perform them remotely without needing to travel to a workplace every single time. The ability to monitor remotely allows one to oversee operations, departments or workers that were out of sight within the traditional approach. In the case of "Smart headband for fatigue risk-monitoring", the

technology allows for monitoring of remote transport workers, who, at the same time, tend to be highly exposed to various OSH hazards. Another technology, described in the case study "Smart armband for real-time data analysis for health & safety", allows for monitoring of ranch and farm workers travelling with cattle by multiple sources of transportation (including horses). The solution creates a unique opportunity to observe OSH risks faced by workers whose situation would otherwise be difficult to monitor or in whose case OSH monitoring without an innovative technology would be significantly less accurate. While the possibility of remote inspections is appreciated, it is important to balance on-site and off-site internal inspections to capture aspects that are beyond technology functioning.

Additionally, data gathered via OSH technologies allow the **organisation of the OSH process based on 'hard indicators', which are usually unavailable in traditional OSH monitoring technologies**. Good examples are wearables that allow for monitoring workers' fatigue or stress via EEG. Traditionally, the only way to analyse such factors are *questionnaires or direct conversations* with workers, which are both much more costly and subject to interpretations. In the case of technologies that monitor the working environment, this allows constant monitoring of chosen indicators, which, in the case of traditional approaches, would be captured with less frequency, with lower precision or not at all. For example, data gathered from the technology presented in the case study "Smart headband for fatigue risk-monitoring" allow for better planning of long routes for transportation workers; its technology allows companies to plan operations based on a technology-gained understanding of when their employees are most vulnerable to fatigue. The comprehensive monitoring system of the case study "Assisted reality device for remote OSH assessments & audit" and an organised monitoring hub allow for accumulating all data monitored over time and indicators. The system enables tracking of all alarms, changes and accidents and sound assessment of OSH processes over time, facilitating better planning and increasing safety. Of course, such functionalities pose challenges, which are discussed in the sections below.

Further, gathered data allow OSH professionals to **enhance compliance with any legal, including health and safety, requirements**. Smart digital systems can enhance compliance management by providing accurate records — automated data collection can help maintain accurate records for compliance with safety regulations — and simplifying the audit process by providing comprehensive and organised data. Consequently, transparency and accountability can be improved. While gathered case studies did provide direct examples of using the reports/part of the report as proof of compliance during labour inspection visits, the interviewees mentioned that OSH professionals extract specific data to fill in the documentation. Such a possibility was appreciated with technology in the case study "Preventing hand-arm vibration syndrome" dedicated to capturing vibration, which supports the risk assessment process dedicated to mechanical vibrations, considering working practices, equipment and unusual working conditions.

Extensive use of data, supported with AI and ML, helps OSH professionals to **better understand a situation in their companies**. That helps to **adjust company-level systems, training and internal procedures to further improve safety in the workplace**. Several technologies provide better *OSH guidance* for the employees, leading to improved employee performance. A good example is the technology in "Wearables to monitor & improve posture – ergonomics", that , thanks to careful monitoring of behaviour, teaches workers more ergonomic work practices that are, in the long run, **not only safer but also more efficient**. Equally, technology described in the case study "Preventing hand-arm vibration syndrome" allows OSH professionals to guide workers through the activities when they are exposed to vibrations. In most of the technologies presented in the study, OSH specialists have access to different data and analytics, which give them an opportunity for **better worker guidance**.

Technologies create various **opportunities for labour inspection authorities** as well. With new issues covered, authorities are able to monitor a broader set of OSH aspects. Most of the technologies are associated with collecting large amounts of new data. In case that OSH labour inspectors could have access to those reports, authorities could react earlier, as well as monitor the evolution of the situation over time. In the long run, technologies could facilitate decentralisation of inspection procedures.[14]

[14] See more in: EU-OSHA – European Agency for Safety and Health at Work, *The future role of big data and machine learning in health and safety inspection efficiency*, 2019. https://osha.europa.eu/en/publications/future-role-big-data-and-machine-learning-health-and-safety-inspection-efficiency

4.1.3 Opportunities for workers

Smart digital OSH systems can promote workers' safety and health. Even though most of the technologies are in a relatively early stage of implementation, there is already strong evidence that the number of accidents and persons injured has significantly decreased after the deployment of the systems in companies as reported in the case studies. For example, one of the employers in the case study "Event recognition for improved safety management" reported a 40% decrease in unsafe events and an 80% reduction in incidents over three months.

Workers benefit from **a shift in the OSH paradigm supported by technologies**. Since *workers' wellbeing* is broader than preventing accidents, the workers' OSH impact can be seen, especially considering the long-term perspective.

Another non-tangible worker impact is their **better OSH awareness, translating into improved health and safety provision in the long term**. Workers become more engaged in their own safety, leading to a culture of proactive safety behaviour, and real-time feedback increases awareness of proper ergonomics and promotes preventive measures. For example, the technology in the case study "Smart armband for real-time data analysis for health & safety" has a voice function that allows workers to send voice memos to their supervisors or other dedicated workers. Interviewees mentioned that after using the technology, workers became more alerted and aware of health and safety and reported more potential risks. In the long term, this may contribute to a safer environment, better health, and a more developed health and safety culture overall. In the case of technology that allows ongoing monitoring, such as in the case studies "Wearables to monitor & improve posture – ergonomics" and "Preventing hand-arm vibration syndrome", receiving feedback on real-time risks or their activity is reported to translate into overall higher caution among workers. Additionally, the available analysis of the data may translate into better habits. Indeed, data on fatigue in case "Smart headband for fatigue risk-monitoring" allow individuals to understand and improve their personal wellbeing, including dietary habits, sleep schedules and exercise routines.

Interestingly, OSH monitoring technologies allow the inclusion of a wide range of workers in OSH processes, creating a **chance for better inclusiveness of the health and safety procedures accessible to workers of varied genders, body sizes and migrant statuses**. For example, in the case "Smart armband for real-time data analysis for health & safety" the system was designed based on the analysis of how workers move in the workplace, allowing developers to decide on the right placement of a wearable on the body, based on the perspectives of different workers. Ultimately, the developers chose an armband that comes in several sizes and is more suitable for all workers. Equally, in the case of "Smart headband for fatigue risk-monitoring", their device is a headband that can be adjusted to employee head size. The device presented in "Smart insoles for lone worker protection" is adapted to each worker's shoe size, to facilitate workers of different heights and shoe sizes.

4.2 Challenges

4.2.1 Challenges for OSH

Several common challenges appear in virtually all the case studies on new technologies for OSH systems. **The main challenge seems to be privacy and data protection.** Almost all the systems involve monitoring of workers, not purely their working environment. Therefore, it is crucial to carefully develop and implement the system as well as establish a data protection scheme to address two major challenges: legal risks and end-user resistance.

Legal consequences are particularly relevant in relation to legislation on data protection, such as in the EU's GDPR, as well as national frameworks. Possible legal provisions may influence OSH impacts**.** For example, in the case of applications monitoring emotional wellbeing, the development and uptake could be critical in the context of the AI Act. Annex III of the AI Act comprises eight areas in which the use of AI can be particularly sensitive and lists concrete use cases for each area. According to that, AI systems used in the areas of employment and biometric identification, among others, will be classified as **'high-risk'** and carefully assessed before being put on the market and throughout their life cycle.

These types of AI systems will also be required to be registered in an EU database.[15] With its approval, the EU aims to effectively regulate the development and use of AI-based systems in Member States to ensure that AI systems used in the EU are safe, transparent, traceable, non-discriminatory and environmentally friendly. The systems should be overseen by people, rather than by automation, to prevent harmful outcomes. This will focus on mitigating the risks of AI by classifying various systems and mandating developments and use requirements.[16]

Companies in this study without the high-risk qualification still mentioned varied legal and regulatory frameworks across the countries as potential challenges. Notably, some developers, such as in case study "Wearables to monitor & improve posture – ergonomics", perceive more strict regulations as business opportunities to acquire new clients.

Cybersecurity is a related, though separate challenge. All the case studies presented require collection of large amounts of data, which should be carefully protected by a company implementing a technology. This is most particularly clear for case studies "Event recognition for improved safety management" and "An OSH smart control centre", since those companies tend to collect complex datasets that if leaked could expose companies and workers to particular risks. The devices introduced by the smart digital OSH systems and their data can be targets for cyberattacks, risking data breaches and unauthorised access to sensitive information, or even potential sabotage of safety systems by malicious actors. Therefore, organisations implementing such technologies (deployers) have to invest not only in the technology itself but also in hardware and know-how related to cybersecurity. Adequate measures for securing data need to be implemented and communicated to workers in order to avoid psychosocial effects such as stress and anxiety.

Most of the technologies described require the active participation of workers. Therefore, overcoming **end-user resistance** is a crucial success factor for their implementation, thus gaining the potential OSH benefits for both workers and deploying companies (employers). **Concerns over data privacy are among the most important barriers. This is particularly relevant to technologies that collect non-standard data**, such as in case study "Smart headband for fatigue risk-monitoring", which uses EEG to monitor workers' brain activity. Such data can potentially be used to analyse off-work worker behaviour, which is a valid concern for workers. To address those concerns, the smart digital OSH system must be **carefully designed to anonymise and protect data and educate workers and employers on risks and opportunities**. On the one hand, the collection of sensitive data carries a promise of creating a safer working environment. On the other, it opens a vast space for potential misuse of data, including d*iscrimination* against employees whose vitals do not appear optimal against whatever benchmarks the user company establishes, as has been raised before.[17] This example illustrates how workers could perceive a system, and how important it is to transparently communicate to workers the system's purpose and the algorithms used, in the interest of avoiding psychosocial risks.

Potential technical issues highlight the risks of **over-reliance on technology**. As with any system, there is a possibility of technical failures, which could lead to unmonitored risks or disruptions in the monitoring and feedback process. Devices such as wearables may fail or provide incorrect data, or the limited battery life can affect their continuous monitoring capabilities, leading to potential safety risks. Smart OSH monitoring systems often rely on internet connectivity, which may be disrupted. Adverse conditions may affect the performance of devices and/or challenge their durability and resilience in rugged environments. Apart from hardware failures, software issues are also possible. There is a need for updates, maintenance and technical support to ensure the system continuously serves its purpose. Adequate resources should be allocated for system upkeep, which was reported as a barrier for implementation, as described in section 3.

Other challenges for OSH relate to **potential false positives and negatives**. Incorrect alerts can cause *unnecessary panic*, while on the other hand, missed alerts can lead to *undetected hazards*, leaving workers vulnerable to potential dangers. Frequent false alarms can *desensitise* workers, making them more likely to disregard future alerts, which undermines the system's overall effectiveness. Moreover,

[15] Ibid.

[16] Europarl.europa.eu (2023). EU AI Act: first regulation on artificial intelligence. https://www.europarl.europa.eu/news/en/headlines/society/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence

[17] See: Farahany, N. A. (2023). Neurotech at work. Harvard Business Review. https://hbr.org/2023/03/neurotech-at-work

unnecessary alerts can *interrupt workflow, reducing productivity and causing frustration*. The limitations of systems in capturing the full context of on-site conditions, such as missing subtle but critical safety issues that a human auditor might detect, further highlight the importance of integrating new systems into existing frameworks to ensure comprehensive workplace safety.

The introduction of new systems asks for **adequate integration into existing (OSH) infrastructure**. Issues may be related to **interoperability**, because compatibility with existing systems and tools needs to be ensured, and data from diverse sources need to be integrated. Challenges also relate to the **adaptation** of the existing system — there is an inherent lag in introducing the system to new workplace environments, and the technology may require considering new risks and regulations.

Considering the accessibility of innovative OSH systems for large, medium and small companies, **comprehensive technologies covering several OSH risks may be important**. Some technologies cover similar safety issues, while others focus on specific aspects such as exposure to poisonous gases ("Smart sensors for hazardous gases"). A wide range of available solutions could make it harder for companies to invest in any specific system. It could also be difficult to use more wearable devices simultaneously. Therefore, especially considering SMEs, it would be welcome to choose either one technology addressing specific company needs or 'have it all' technologies. Therefore, as described in section 4.1.1 (Opportunities for OSH), to unleash technology's potential, using reactive and proactive measures for OSH technologies and 'having it all' may trigger SMEs to consider OSH technologies.

4.2.2 Challenges for OSH management

OSH management requires that preventive measures be implemented to eliminate hazards and/or reduce risks, according to the so-called **hierarchy of controls**.[18] An often-raised challenge relates to the fact that smart OSH monitoring systems may **blur OSH responsibility** in practice by making employers increasingly reliant on the systems at the expense of other (collective) OSH measures. Potentially, employers may omit adequate risk assessments, may fail to adopt organisational measures or treat the smart systems as a **substitute for other OSH obligations**. Workers might also become overly reliant on the system, potentially neglecting basic safety practices and human judgement, or may feel protected and take greater risks. The case studies highlighted that the companies that develop smart systems and those that deploy them in the workplace are aware of these challenges and risks. Indeed, as noted in section 3, system developers and deployers (employers) pay much attention to cooperating in order to understand the workplace needs, effectively integrate the new solutions into the existing OSH framework, and provide adequate training and workplace resources. Companies were aware of the need to ensure that systems complement rather than replace human judgement.

With new technologies, proper training of workers is even more critical. Most designers are aware of possible challenges in technology at the company level and propose different approaches to address that issue. In most cases, the induction process runs in close cooperation with designated workers, frequently OSH professionals. Therefore, their insight into existing company OSH processes, risks and challenges is crucial. Additionally, in many cases, **the OSH professional was identified as the focal point** between workers and developer's representatives, therefore being at the frontline in case of any worker concerns.

Deployment of most technologies requires a careful *calibration* of the products. Systems are as efficient as the data they use. Therefore, **OSH professionals must have a lot of knowledge** of the deploying company's characteristics and specific risks and spend significant time adjusting products to those specific issues. In particular, that challenge is explicitly mentioned by developers of large-scale AI-supported databases, such as in "Event recognition for improved safety management" and "An OSH smart control centre". The large volumes of data generated by the new OSH monitoring systems can lead to *information overload*. Data management and analysis, as well as ensuring that the collected data are relevant and actionable for improving safety, can be challenging.

To overcome challenges, the key issue is **an ongoing user–developer cooperation at all stages of the deployment**. In order to fully reach the potential of those solutions, *the developer should have knowledge on the needs and specifics of the deployer (employer)*. That fact creates several challenges

[18] The hierarchy of controls includes: 1) elimination, 2) substitution, 3) engineering controls (e.g. ventilation, scaffolding, safety nets), 4) administrative controls (e.g. task rotation, risk assessments), and 5) personal protective equipment.

for OSH professionals and possible workers using the new system. Firstly, they have to quickly learn the new technology and acquire skills that did not use to be required for their jobs. Even if a new technology is built into existing company systems, it usually includes new elements, for example, a new interface such as in case study "Assisted reality device for remote OSH assessments & audit". *Good technical knowledge* is crucial for both effective use of OSH systems and support to the developer team. Secondly, OSH professionals must gain a deeper understanding of their needs. That usually requires a significant amount of additional work, as well as obtaining new skills.

Another challenge for OSH professionals stems from having to **balance between monitoring the safety of workers and not their performance**. With technologies monitoring various aspects of employee characteristics, OSH professionals can have access to data that significantly go beyond what is necessary for health and safety at the workplace. In some cases, for example, an EEG as in "Smart headband for fatigue risk-monitoring", such data can even reveal highly sensitive information on employees' lives outside the workplace. As a consequence, for both legal and trust reasons, OSH professionals have to pay much more attention to their work, to **ensure that workers' personal data are safe and used only for the purpose of safety**.

In the long run, there exists a chance that a technology supported by **an AI would assist OSH professionals as** some of their current tasks could be automated[19]. Several aspects of technologies presented in the case studies already prove to be more efficient than a person, for example, in "An OSH smart control centre", the technology can automatically identify a risky behaviour at the workplace without any human intervention. However, for the time being, this should not be considered as a real challenge. Furthermore, since the ***calibration*** is key for effective use of a technology, the role of OSH professionals is even more important.

Labour inspection authorities also face challenges related to OSH technologies, as they could create an **entry barrier for inspectors**. In order to appropriately address the signals reported by companies, OSH inspectors need to have advanced knowledge of both challenges and use of technology itself. Possibly, they also require new procedures, in response to psychosocial risks or risks related to data protection.

Inspectors should also be aware of the risk of over-reliance on technology. Reports generated thanks to the use of new technology may potentially hide problems in other areas, **therefore they should be used as a support to inspection rather than as its replacement**. It should be further noted that companies that are the most likely to employ advanced OSH technology may be perceived by labour inspection authorities as subjects of lesser concern, since they usually already follow the basic OSH procedures. Nevertheless, authorities need to be mindful of potential risks linked to data inaccuracy and manipulation.

4.2.3 Challenges for workers

While the study data have largely been collected from developers, deployers') approaches and impact on workers have been central to the study. Workers' concerns have been voiced in several case studies, indicating common **reservations towards the daily use of smart digital systems**. Across companies, **workers express concerns over monitoring of their productivity and possible data misuse**, which link to psychosocial risks such as **stress and work alienation**.

In the case study "Preventing hand-arm vibration syndrome", workers report **concerns about sharing their data on productivity and location with their managers**. End-users (workers) in case study "Smart headband for fatigue risk-monitoring" tend to worry over their fatigue (information processed from brainwaves) being collected and processed and their activity and productivity tracked and monitored; as mentioned in the interview, **workers worry about 'getting tired and getting fired'**. Similarly, users in case study "Smart insoles for lone worker protection" voiced the fear of increasing workers' workload due to the belief of being better protected, for example, **asking one worker to do a job usually done by two**. In general interviewees mentioned the concern of constant monitoring, potentially infringing on privacy and fostering a sense of surveillance.

[19] EU-OSHA – European Agency for Safety and Health at Work, *Advanced robotic automation: comparative case study report*, 2023. https://osha.europa.eu/en/publications/advanced-robotic-automation-comparative-case-study-report

Other end-user concerns were related to **worker comfort**, which can adversely impact their performance. If the technology impacts workers' efficiency — even subjectively — employers would be more hesitant to implement it since it would require them to work more. While the *perception of increased workload, or uncertainty of skills, can cause stress and psychosocial risks,* one should note that the *devices used in smart monitoring systems can pose risks to physical health and safet*y. Depending on the device, the risks may potentially include discomfort, skin irritation, increased cardiovascular stress, biomechanical constraints and musculoskeletal disorders (MSDs). In particular, all kinds of wearables directly impact the comfort of working. Some designers directly point to this problem, as in the case of "Smart insoles for lone worker protection", which puts the comfort of insoles in first place.

Another **common concern for workers is data privacy and security**. In case study "Smart armband for real-time data analysis for health & safety", some end-users voiced their opinions that as the technology can capture their surroundings, **it might track them**. Users of the technology described in the cases "Smart headband for fatigue risk-monitoring" *fear sharing their data on health issues*. In the cases of "An OSH smart control centre" and "Event recognition for improved safety management", both systems collect a wide range of sensitive metadata. Especially in the case of "An OSH smart control centre", there have been concerns over potential *security risks* associated with large-scale operations. These threats include terrorists or other actors hijacking commercial drones to conduct rogue operations and intercepting sensitive data.

Besides the challenges directly reported by interviewees, the collected data foreshadow possible **challenges around protecting workers' voices in decision-making and their agency more generally**. Innovative OSH monitoring systems provide employers with powerful tools to collect data on workers and workplaces, further increasing the **power imbalance** between employers and workers. Various insights and conclusions can, be drawn based on these data as to various company operations, , to help improve OSH results. Evidence-based decision-making carries immense potential, provided that the evidentiary basis for decisions is critically interrogated. **Over-reliance on (largely quantitative) data** generated from innovative OSH monitoring systems, **without seeking direct feedback from workers, may lead to misinterpretations** and decisions that are not optimal, both from an OSH but also a business perspective. If workers are **not consulted but are presented with algorithm-generated decisions about their professional lives,** they may feel **deprived of agency, devalued and demotivated**. This could reverse if not all then some of the OSH gains from implementing the new system. The implementation of such systems should thus come alongside **procedures for worker engagement** beyond the induction phase; and as mentioned in the study ***"****the more intrusive the data collection and possible implications of the system's use for company operations, the higher employee engagement should be"*. Moreover, engaging workers may ensure that responsibility for OSH does **not shift from the collective to the individual level**.

Table 1: Worker concerns and identified solutions / approaches

Worker concerns	Identified solutions / approaches
Sharing their data on productivity, 'get tired, get fired' or monitoring-induced increase of workload.	Full transparency on what data are gathered and what are not.
Sharing their data on location.	Organising data monitoring around devices/ environments, not chosen employee.
Sharing personal data potentially related to health.	Induction phase and communication measures.
Hijacking the data by third parties.	Make the commitment in writing that the technology will not be misused for any purposes; provide safety measures from hijacking the technology.
Inconvenience in technology use (lack of skills, insufficient skills, changes to the working routine, physical inconvenience caused by wearing the device).	Adapting devices for the convenience and comfort of an employee.

As described in Table 1, **several measures addressing worker concerns have been identified, many focusing on what data are gathered and how they are stored**. Additionally, the employers should be fully transparent on the capabilities and limitations of the AI models (accuracy/correctness, robustness and fairness), how data are used and securing the option to delete their data upon worker request. In the case "Wearables to monitor & improve posture – ergonomics", gathered data are anonymised. In the cases "Smart headband for fatigue risk-monitoring" and "Smart armband for real-time data analysis for health & safety", data monitoring is related to the device, not the person using the device, putting in another safety layer for worker anonymity. In the case study "Smart armband for real-time data analysis for health & safety" specifically, the device is assigned to the worker randomly each day before starting a shift. Therefore, the dashboard presents data, for example, on temperature, concerning the chosen device, not a worker. Ultimately, it is possible to investigate which device is used by which worker, which adds an additional protective layer, supporting workers' anonymity. Indeed, in case study "Smart armband for real-time data analysis for health & safety" deployers indicates that the function could be used when crucial, as it was activated in the COVID-19 pandemic when it was necessary to determine workers who have been in touch with one of their infected colleagues. In case study "Smart insoles for lone worker protection", the geolocation function of the smart insoles technology only activates in the case of an alert, protecting workers' right to privacy. Alerts are triggered either by workers feeling in danger or in case the technology senses unusual employee behaviour, such as lying on the ground for some period of time. This approach to the alerts allows for minimising the risks of overusing geolocation function. Moreover, while the data are processed on a "Smart insoles for lone worker protection" cloud platform, the data are entirely the deployer's property. Other than the approaches to implementation described in section 3, **encouraging the leadership of the implementing company to commit in writing that technology will not be misused for any purposes** is another possible approach suggested in the case studies. Notably, these solutions come from worker representatives.

While the solutions listed above offer safeguards that can secure workers interests to some extent, they possibly miss a key factor that emerges from the information collected in the study. The reported worker concerns centre around a **fundamental issue of trust between workers and employers**. The level of trust may differ between companies and individuals. And possible distrust is underlined by interests that are not entirely overlapping, even if they ideally should be. In this context, to truly address some of the workers' concerns, the **smart digital OSH systems should incorporate solutions that, in a way, guarantee trust**. This includes building in functionalities that give the workers *the power to see specific*

employers' actions on their data and to control data processing (including discontinuation) when processing does not have a legitimate basis or exceeds its stated purpose. Given the *power imbalance*, the **legal systems should also be prepared to protect workers who assert their rights in this way**. Besides legislation, there is also a clear role to play for *labour inspections* in how smart digital OSH systems are implemented and used. However, for labour inspectorates to play this role, they need to be equipped with expertise and resources. In this sense, legislation and labour inspection practices need to keep pace with the fast development of smart monitoring systems and their use in the workplace, so as to ensure integration in an effective OSH management system, based on collective/employer responsibility and in the context of the hierarchy of controls.

5 Conclusions and future considerations

The overview of the case studies covered through this research sheds light on the **diverse array of smart monitoring systems that use new technologies and tools currently developed and deployed to improve OSH**. These systems fulfil the definition of new OSH monitoring systems, as they aim to identify and assess risks, prevent harm and minimise workplace hazards.

5.1 Proactive and reactive functions of smart systems for OSH

Considering the broad implications, one should note that, overall, **the driving force behind implementing smart digital OSH systems is the desire to enhance health and safety within workplaces** — a goal that in itself is not new but can be achieved by leveraging cutting-edge technologies.

By providing real-time data, insights and recommendations generated by the OSH **monitoring systems can greatly contribute to a proactive approach for OSH**. Rather than merely reacting to incidents, deploying companies can anticipate risks, prevent accidents and safeguard their workforce. The case studies exemplify how technology **empowers risk identification and early detection**, which leads to the prevention or avoidance of harm. The range of risks covered by the case studies encompasses:

- individual and collective harmful exposures and environmental levels,
- exposure to ergonomic risks,
- plant and premise-related risks,
- hazardous worker behaviour,
- individual wellbeing and fatigue risks, and
- psychosocial risks.

Because of the technological developments, accurate and fast insights can be generated when certain parameters *exceed specific thresholds or norms*. As shown in some of the case studies, risk detection can further be strengthened by AI, ML or predictive algorithms, which can analyse complex, large-volume of *data to forecast potential risks* and provide behavioural insights.

Moreover, in terms of implications for OSH management, the systems bring **operational opportunities for companies and OSH professionals**. For example, some systems allow *internal risk assessments, inspections or audits to be performed remotely*, saving time and resources that would otherwise be necessary for travel to distant sites of operation. Remote technologies also have the potential for participation of external parties in such assessments and inspections. Other systems can improve the efficiency of compliance monitoring by identifying if protective gear is worn, procedures are followed, and equipment is operated correctly.

Furthermore, the extensive use of data, supported by AI and ML, can help OSH professionals and the company better **understand the situation in their workplaces, facilitating continuous improvement** — that is, allowing to adjust company-level systems and internal procedures to further improve safety in the workplace. Together with the enhanced potential to present information tailored to the needs of specific workers or groups, digital technologies can strengthen the training functions of OSH systems.

The case studies did not directly identify the systems being used for the purposes of labour inspectorates. However, such use is clearly conceivable, and an EU-OSHA report has mapped examples.[20]

As the case studies exemplify, in practice, the smart digital systems often **serve multiple OSH purposes and combine more than one digital technology**. Often, this is not limited to monitoring for multiple risk factors within the systems' proactive functions, but **also integrating functions that fall into the category of reactive OSH monitoring**. By enabling easy signalling and precise localising of emergencies and helping to respond to such events, the systems can minimise the consequences of harm that occurred at the workplace. New technological capabilities can also enhance how accidents are investigated, reported on and used to support the improvement of OSH. While new OSH monitoring systems bring many opportunities, they also pose challenges to OSH. The analysis of the conducted case studies shows that **key to overcoming these challenges is how the systems are integrated into existing OSH frameworks**.

5.2 Integrating smart digital systems for OSH into existing OSH frameworks

By highlighting the multifunctionality of the solutions covered by the case studies, we aim to argue that they are in fact **integrated systems** aimed at offering comprehensive solutions that leverage new technological advancements and a combination of technologies to solve the specific needs of an industry, company or workplace. By providing accurate and detailed monitoring of various parameters, they can greatly enhance OSH practices and contribute to safer work environments. However, OSH is a process or cycle, rather than a compartmentalised intervention, and while able to perform many functions, the systems discussed are not able (nor do they aim) to provide all-in-one solutions. An OSH framework should be viewed as a means of continuous learning, which involves a number of dependencies, processes and practices. Thus, it is a framework that **encompasses a wider range of elements than a single smart monitoring system**.

Examining the case studies reveals that these monitoring systems are often **custom designed to address specific purposes or monitor particular parameters**. Whether in specific industries, sectors or individual companies, these systems are tailored to meet unique requirements. Their richness of information allows for targeted interventions and proactive measures. For instance, a system designed to monitor noise levels in a manufacturing facility may differ significantly from one focused on ergonomic assessments in an office setting. This adaptability can potentially **ensure that OSH monitoring aligns with the specific needs of each context**.

While the systems are transferrable to a degree (the more similar the tasks, applications or sector, the higher the transferability), the case studies highlight that implementation at a specific workplace requires some consideration. Close cooperation between the developer and deployer, as well as **common understanding of the needs and priorities are vital to guarantee the successful implementation of the solution**. System designers and developers as well as the deployers/users have to address needs at the company employer (high-management) level, at the OSH professionals level and at workers level. In the examined cases, this was often conducted through iterative interactions between the developer and deployer, which served in assessing the system's effectiveness and identifying room for improvement.

The importance of understanding needs and priorities is linked to the fact that data collected by smart digital systems can potentially be inaccurate, limited or biased, which ultimately can bring risks to safety and health. **Over-reliance on the OSH systems can lead to complacency and a false sense of security**, which can be particularly dangerous in high-risk work environments. Therefore, it is crucial to use these systems as a supplement to, rather than a replacement for, traditional safety measures and human judgement that form elements of a broader OSH framework.

[20] EU-OSHA – European Agency for Safety and Health at Work, *Smart digital monitoring systems for occupational safety and health: uses and challenges*, 2022. https://osha.europa.eu/sites/default/files/Smart-digital-monitoring-systems-uses-challenges_en.pdf

5.3 The workplace as a data-rich environment

The introduction of digital technologies to the workplace brings multiple opportunities and challenges, as discussed in section 4 (OSH impacts) of this report. The underlying change is that smart digital systems — as an element of broader OSH frameworks — transform the workplace into a data-rich environment, and in consequence, **the primary considerations relate to the privacy of workers' data and potential misuse of such data**.

The case studies reveal that, often, smart digital OSH monitoring systems, while serving to increase workers' safety and broader wellbeing, are seen (and sold) as tools of which the employer is the primary user. Workers can be and are empowered to contribute at some stages, for example, on the systems' design or implementation at a workplace, and trained to use the systems, yet the decision of introducing a new system lies with the company.

The systems provide companies with knowledge, which may be significant to improve OSH, but the insights that they gain on workers deepen the asymmetry inherent in the employment relationship. With some types of systems, such as those collecting biometric data, this asymmetry can reach a level where employers could know much more about their workers than the latter know about themselves.

The implementation of such systems should thus come alongside procedures for worker's engagement beyond the induction phase; and the more intrusive the data collection and possible implications of the system's use for company operations, the higher the worker engagement should be. The specific measures and procedures will always depend on the rationale behind the system's introduction, but they need to also address what data are gathered and how they are treated, stored and processed. The examined cases highlight two approaches to these issues: **a) privacy by design**, which entails measures such as data anonymisation, data minimisation, compliance with the GDPR and secure storage of data; and **b) privacy by choice**, which focuses on restricting data access for specific positions and users (e.g. OSH professionals, managers, etc.).

Concerns about data privacy or misuse brought up by workers may be perceived as resistance to new technologies. This perception testifies to a possible implicit acceptance of the inevitability of these systems being implemented by employers. Yet, the concern around allowing employers access to ever more spheres of workers' lives, including mental health, are serious and lead some to argue against the use of some technologies. This highlights the **need to consider data privacy when introducing smart digital systems at the workplace, and potentially developing guidance or regulations that would safeguard workers' rights**. Smart OSH monitoring systems should incorporate functionalities that give the workers the power to see specific employers' actions on their data and control data processing (including discontinuation) when processing does not have a legitimate basis or exceeds its stated purpose. Given the power imbalance inherent in the worker–employer relationship, the legal systems should also be prepared to protect workers who assert their rights in this way. Besides legislation, there is also a clear role to play for labour inspections regarding smart digital OSH monitoring systems.

5.4 Takeaways for development and implementation of new OSH monitoring systems

Based on the case studies, a number of cross-cutting insights for the development and deployment of smart digital OSH systems can be formulated. To a degree, these overlap, which highlights that some issues, such as data security and privacy, and cooperation, should be considered both by the system developers as well as deployers – and at the workplace the employer and the worker.

Considerations for the development and implementation of smart digital OSH systems:

Box 1: Considerations for developers of smart digital systems

System design and development should ensure the following features:

INTEGRATION AND CUSTOMISATION

- **Integrated** into organisations' **existing systems to optimise OSH processes** and to form a holistic view of safety and health across all workplaces, prevent migration issues and anticipate (future) scalability needs.
- **Customised** to fit to specific organisational and individual needs.
  - **Tailor-made** by embedding **diversity and inclusion principles**.
- **Intrinsically designed to avoid negative consequence** by the use of the new OSH monitoring systems for performance measurement.
- **Foster proactive safety management** to emphasise mitigation of risks before incidents occur, demonstrating clear advantages over reactive technologies.

DATA SECURITY AND PRIVACY

- **Compliant** with the latest relevant legislation (EU, national) on issues such as data privacy, (AI) provisions, etc.
- **Fostering a privacy-centric design** that addresses and alleviates worker privacy concerns, embedding privacy by design where feasible or preferred.
- **Minimising and/or anonymising the collected data**, preventing the collection of data not relevant for OSH and making certain features, such as geolocation data, available only in specific circumstances such as for alerts.
- **Transparent by clearly informing users** about the data privacy and management aspects of the systems, to maintain and build trust among the workforce.
- **Ensure robust data security measures** within the system to address potential cyberattacks and ensure user data confidentiality.

RELIABILITY AND USER FRIENDLINESS

- **Ensuring user comfort** in the design of the wearables and devices.
- **Focused on safe interfaces** by a user-centred, ergonomic and intuitive design for the interfaces to minimise physical and operational hazards.
- **Enhance accuracy** through continuous empirical validation and refinement of algorithms and data sources, ensuring reliable results for clients' needs.
- **Compliant with relevant standards** for effective operation in **challenging environments and remote areas**.
- Adherent to transparent and rigorous processes to ensure **clarity in the journey from data to interpretation and to avoid potential biases, including unintended** ones.

COMMUNICATION AND COOPERATION

- **Clear about limitations** of the systems to potential clients to prevent misunderstandings regarding their usage.
- **Involving the client (deployer)'s representatives**, in particular users and workers, in the development stage.
- **Transparent by implementing measures** to provide clients with **clear insights** into how the systems operate and the **underlying algorithms**, fostering trust and understanding.
- **Establishing a step-by-step cooperation framework** with the users/deployers, emphasising efficient **change management** and communication.
- **Offering ongoing support** to deployers throughout the implementation phase, such as trial periods, test phases, tutorials, workshops, user guides, on-site visits and so on.

Box 2: Considerations for users/deployers of smart digital OSH systems

Employers should in system deployment incorporate and ensure the following:

DATA SECURITY AND PRIVACY
The implementation of the system should be:

- **Compliant** with the latest European and national legislation on data privacy and relevant (AI) technologies.
- **Minimising and/or anonymising the collected data**, preventing the collection of data not relevant for OSH and making certain features, such as geolocation data, available only in specific circumstances such as for alerts.
- **Ensuring robust data security measures** within the system to address potential cyberattacks and ensure user data confidentiality.
- **Engaging workers or their representatives to address concerns** over personal data collection, provide comprehensive information and establish clear policies on data usage and workers monitoring, ensuring transparency and consent.
- **Establishing clear protocols and procedures** for addressing any concerns or issues raised by workers related to privacy, data security or ethical considerations.

PURPOSE OF SYSTEM USE AND PROACTIVE SAFETY CULTURE

- **Safeguard workers' rights** and clearly inform workers about the data privacy and management aspects of the systems, adopt a transparent approach to build trust among the workforce.
- **Support procedures and policies** that define the purposes and scope of system use and clarify who **owns the collected data,** and communicate these procedures and policies clearly.
- **Separate the digital OSH system from other information management systems**, for example, those related to measuring the workers' performance, to ensure transparency and overcome workers' resistance.
- **Provide comprehensive training** to workers on the proper use and interpretation of the system, emphasising its role as a supportive tool rather than a surveillance mechanism.
- **Act on the data insights to foster a proactive safety culture** in the workplace, effectively offering support and coaching to at-risk workers.
- **Foster proactive safety management** to emphasise mitigation of risks before incidents occur, demonstrating clear advantages over reactive technologies.
- **Promote balanced vigilance** — encourage a balance between technological reliance and human vigilance through training and awareness programmes.

INTEGRATION WITH EXISTING OSH FRAMEWORKS AND TECHNICAL INFRASTRUCTURE

- **Acknowledge the main responsibility** to ensure safety in the workplace falls on **employers,** and that it cannot be substituted by system indicators.
- **Highlight how the new system supports collective and individual wellbeing**, encouraging workers to take precautions for their own safety while reiterating that **the employer maintains the overarching responsibility for OSH**.
- Introduce the smart digital OSH monitoring systems as an **integral part of a comprehensive OSH framework** rather than as a substitute.
- **Explore avenues to improve system integration (and interoperability)** to optimise OSH processes and form a **holistic view of safety and health across all workplaces**, prevent migration issues and anticipate (future) scalability needs.
- Particularly in life-critical operations, having clear protocols and procedures in place **for addressing any concerns or issues raised by workers related to privacy, data security and ethical** considerations.
- **Conduct regular evaluations and assessments** of the system's effectiveness and impact on workers wellbeing, making adjustments as necessary to ensure its safe and responsible implementation.
- **Allocating sufficient resources** for the proper implementation and regular maintenance of the system and take precautions against potential system malfunctions.

COOPERATING WITH SYSTEM DEVELOPERS

- **Ensure transparent communication with system developers** to receive clear information on limitations and insights into how the systems operate and the underlying algorithms, fostering trust and understanding.
- **Engage workers' representatives and workers during system implementation and deployment** to ensure customisation and tailoring to their needs, as well as reinforce trust and transparency.
- **Establish a step-by-step cooperation framework** with the developer, emphasising efficient change management and communication.
- **Request ongoing support from the developer** throughout the implementation phase, such as trial periods, test phases, tutorials, workshops, user guides and on-site visits.

The European Agency for Safety and Health at Work (EU-OSHA) contributes to making Europe a safer, healthier and more productive place to work. The Agency researches, develops, and distributes reliable, balanced, and impartial safey and health information and organises pan-European awareness raising campaigns. Set up by the European Union in 1994 and based in Bilbao, Spain, the Agency brings together representatives from the European Commission, Member State governments, and employers' and workers' organisations, as well as leading experts in each of the EU Member States and beyond.

European Agency
for Safety and Health at Work
Santiago de Compostela 12
48003 - Bilbao, Spain
E-mail: information@osha.europa.eu
http://osha.europa.eu

Publications Office
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