



Making safety tech work

A practical framework for identifying and selecting safety technology solutions for industry

CAMBRIDGE INDUSTRIAL INNOVATION POLICY | IFM ENGAGE, INSTITUTE FOR MANUFACTURING, UNIVERSITY OF CAMBRIDGE

About the white paper

This white paper was developed by the Global Initiative for Industrial Safety (GIFIS), led by Lloyd's Register Foundation, the United Nations Industrial Development Organization (UNIDO), and Cambridge Industrial Innovation Policy (CIIP). The paper has not undergone a formal editorial review by these organisations, and the views expressed do not necessarily reflect their official positions. The mention of firm names or commercial products does not imply endorsement by the authors or by GIFIS.

This paper has been shaped through engagement with the broader GIFIS community, an international, voluntary network of practitioners working collaboratively to identify practical steps for the safe adoption of new technologies in industry. Community members provided valuable input during meetings held throughout 2025 and 2026 and offered feedback on earlier versions of this paper.

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Who is the white paper for?

This white paper is intended for safety practitioners, particularly those responsible for firm-level safety management and seeking to use technology to make workplaces safer. It also provides a reference for safety technology providers seeking to better position the value of their products and services.

The paper introduces a framework that links safety technologies to their potential effectiveness in improving workplace safety. The framework also supports further return on investment (ROI) analysis by considering costs, implementation effort, and resource requirements. In doing so, it offers a practical tool for more informed decision-making on safety tech adoption. The guide helps practitioners to navigate uncertainty, adopt innovation more effectively, and support safer workplaces, while enabling technology developers to communicate more effectively and position their solutions in industrial contexts.

Executive summary

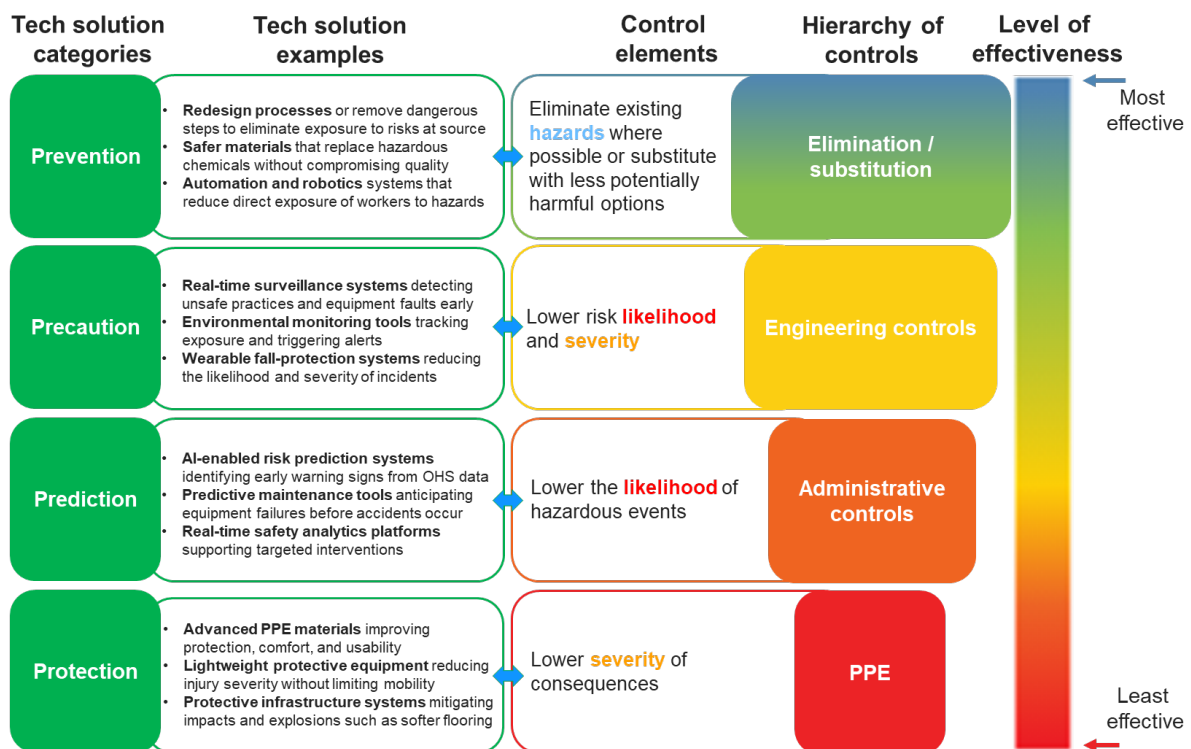
This white paper introduces a generic framework to help industrial users systematically assess the effectiveness of different technology options in addressing specific occupational safety and health (OSH) risks. Work-related deaths and injuries continue to impose a major global burden, while emerging technologies are offering new possibilities for improving industrial safety.

The good news is that a broad range of emerging technologies are becoming commercially available to improve industrial safety, including digital and other technologies such as robotics, wearable devices, and new materials.

Yet, in practice, the adoption of emerging technologies for improving industrial safety is still limited. A key barrier to adoption is the growing mismatch between an increasingly crowded market offering safety tech solutions and the limited visibility industrial users have over their potential safety outcomes relative to the associated costs and implementation effort.

The framework presented in this white paper (Figure E1) is designed to support practitioners to address these barriers to safety tech adoption by establishing a clear link between technology categories and their associated effectiveness. It has also been developed with input from the GIFIS Community of Practice.

FIGURE E1 A FRAMEWORK FOR ASSESSING THE EFFECTIVENESS OF SAFETY TECH SOLUTIONS



Source: CIIP, adapted from WIPO. [Patent Landscape Report - Occupational Health and Safety \(OHS\)](#).

Developed in the 1950s, the Hierarchy of Controls has become a widely used framework for employers across industries to evaluate the effectiveness of safety safeguards. Recently, some organisations have begun applying this framework to assess the potential effectiveness of emerging technologies to give industrial users greater visibility of their safety benefits.

The framework first maps the five tiers of the Hierarchy of Controls (*elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE)*) against three core elements of industrial safety improvement: *hazards, likelihood of occurrence, and severity of consequences*. By linking each tier to the element it most directly influences, the framework helps to explain the differences in the relative effectiveness of the various control mechanisms. Emerging technologies for industrial safety are classified according to the 4Ps of risk management: *prevention, precaution, prediction, and protection*.

Deep dive: technology solutions for fall-from-height risks

A case study of over 19,000 patented technologies addressing fall-from-height risks demonstrates the value of the framework in systematically classifying and reviewing diverse safety solutions. The findings highlight a clear shift from traditional mechanical equipment, such as scaffolds and ladders, towards digitally enabled devices and systems, which offer greater effectiveness in addressing these risks.

Beyond this, the value of this framework lies not only in clarifying the potential effectiveness of different technology options but also in supporting further return on investment (ROI) analysis by taking cost, implementation effort, and other resource requirements into account. In this way, it offers an actionable tool for more informed decision-making on safety tech adoption.

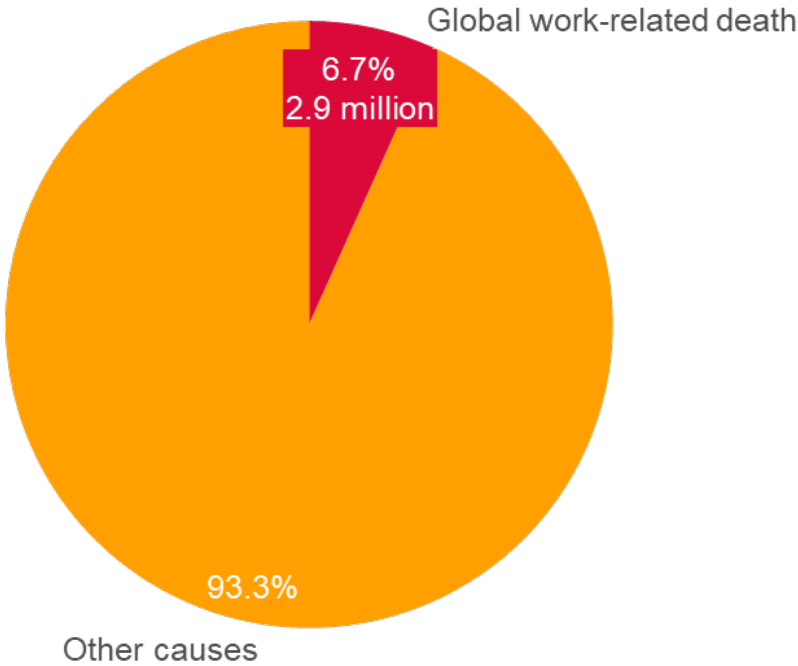
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1. Why do we need to act now? Global trends and challenges in work-related deaths and injuries

The International Labour Organization (ILO) estimates that work-related deaths increased from approximately 2.8 million in 2015 to 2.9 million in 2019, accounting for 6.7% of all global deaths among the working-age population (Figure 1).¹ In terms of non-fatal injuries, the ILO’s estimation shows that 395 million workers sustain occupational injuries each year, many of which are life-altering.² Economically, these fatal and non-fatal incidents translate into significant losses, with poor occupational safety and health (OSH) conditions estimated to cost 4.1% of global GDP, equivalent to more than USD3.2 trillion annually.³

FIGURE 1 SHARE OF WORK-RELATED DEATHS AMONG GLOBAL WORKING-AGE DEATHS, 2019



Source: ILO. [Safety and health at work](#).

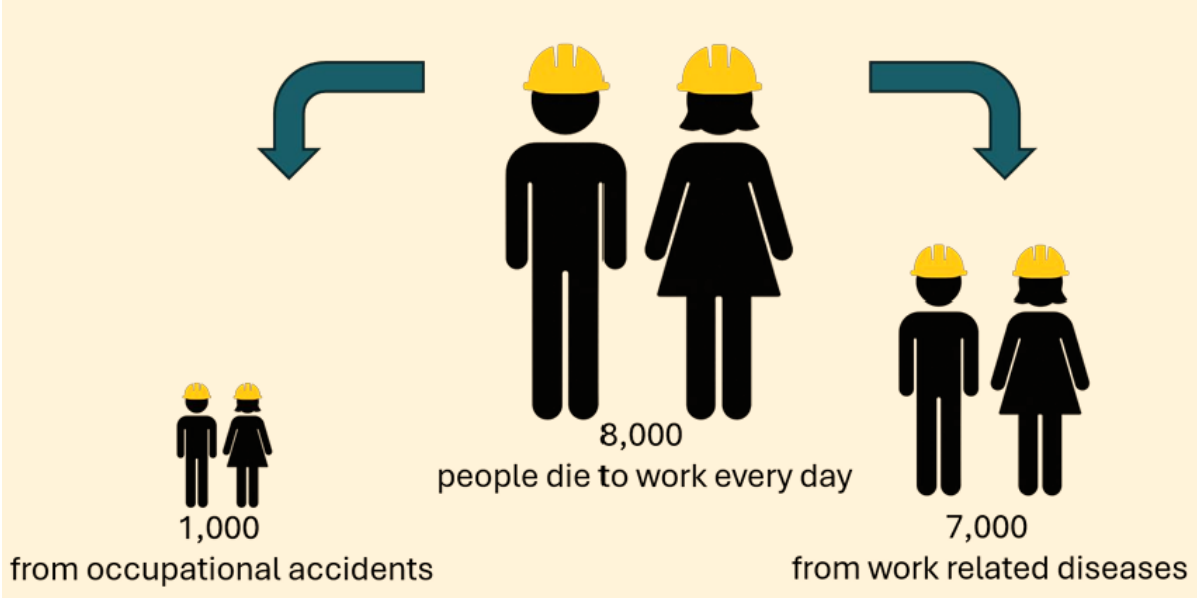
¹ ILO (2025). [Issue Paper: OSH Statistics Supporting the review and update of the international OSH statistical standards at the 22nd ICLS in 2028](#).

² ILO. [Safety and health at work](#).

³ ILO (2025). [Issue Paper: OSH Statistics Supporting the review and update of the international OSH statistical standards at the 22nd ICLS in 2028](#).

Notably, 88.7% (around 2.6 million) of these fatalities resulted from work-related diseases, while the remaining 11.3% (around 0.33 million) were caused by fatal occupational accidents. In other words, around 8,000 people die every day as a result of unsafe and unhealthy working conditions: approximately 1,000 from accidents and 7,000 from work-related diseases (Figure 2).⁴

FIGURE 2 WORK-RELATED DEATHS: ACCIDENTS VERSUS OCCUPATIONAL DISEASES



Source: ILO (2025). Issue Paper: OSH Statistics Supporting the review and update of the international OSH statistical standards at the 22nd ICLS in 2028.

The contrast between fatalities caused by occupational accidents and those resulting from work-related diseases is striking. The leading causes of fatal occupational accidents globally include transport-related incidents, such as vehicle injuries, and falls from height. At the same time, work-related disease deaths are largely driven by factors such as long working hours and are concentrated in three main categories: circulatory and cardiovascular diseases, malignant neoplasms (cancers), and chronic respiratory diseases (Figure 3).

Work-related diseases are often referred to as “silent killers” because they are characterised by long latency periods before symptoms become apparent. These conditions can arise from a wide range of workplace risk factors, including poor ergonomics, prolonged stress, exposure to hazardous chemicals, and excessive workloads.

The effects of exposure to these workplace risk factors may vary significantly among workers depending on factors such as recovery conditions, access to treatment, and other health determinants. For

⁴ ILO (2025). [Issue Paper: OSH Statistics Supporting the review and update of the international OSH statistical standards at the 22nd ICLS in 2028.](#)

example, prolonged exposure to hazardous substances may not immediately reach levels of acute toxicity but can gradually weaken the immune system of inadequately protected workers.

Compared with workplace accidents, it often takes decades for the symptoms of work-related diseases to become apparent. This delay creates a significant statistical blind spot. In many developing countries, where large informal labour markets exist and occupational health surveillance systems are limited or absent, affected workers often leave industrial employment long before receiving a formal medical diagnosis. As a result, these deaths are rarely officially recorded as “work-related”, leading to a substantial underestimation of the true scale of occupational health risks.⁵

FIGURE 3 TOP 10 OCCUPATIONAL RISK FACTORS BY NUMBER OF DEATHS, 2016

No	Top 10 occupational risk factors by number of deaths	Number of deaths, 2016, globally
1	Particulate and gas exposure linked to COPD (Chronic obstructive pulmonary disease)	450,381
2	Long working hours linked to stroke	398,306
3	Long working hours linked to heart disease	346,618
4	Asbestos exposure linked to lower respiratory tract cancer	172,616
5	Vehicle injuries from work-related activities	76,946
6	Pedestrian injuries from work-related activities	72,157
7	Motorcyclist injuries from work-related activities	48,151
8	Silica exposure linked to lower respiratory tract cancer	42,592
9	Falls resulting from work conditions	34,996
10	Asthmagen exposure linked to asthma	29,641

Source: WHO and ILO (2021). WHO/ILO joint estimates of the work-related burden of disease and injury, 2000–2016: global monitoring report.

⁵ WHO and ILO (2021). [Long working hours increasing deaths from heart disease and stroke.](#)

2. Smarter, safer, sooner: artificial intelligence, automation, and the future of industrial safety

Technological developments are reshaping industrial safety by transforming how hazards are measured, monitored, and managed. A key shift is underway – from reactive safety, where company policies are updated after incidents occur, to anticipatory safety, in which systems continuously detect contextual, behavioural, and mechanical precursors to failure and enable earlier intervention.

This transition is underpinned by the growing use of leading indicators, which support real-time monitoring and more preventive, data-driven decision-making. Advances in artificial intelligence (AI) are accelerating this shift, enabling the analysis of large volumes of operational and behavioural data to identify risk patterns that would otherwise remain hidden.

These approaches are particularly relevant in high-risk sectors such as construction, manufacturing, and mining, especially in environments with frequent “struck-by” or equipment-related incidents. However, their relevance extends far beyond these sectors. Organisations across industries can benefit from adopting and adapting practices developed in higher-risk contexts, leveraging technology to strengthen their own safety systems and move towards more proactive risk management.

What is emerging is not a single solution, but a portfolio of technologies, applications, and approaches that, together, are redefining how industrial safety is delivered:

- **From reactive to anticipatory**

A central enabling technology is predictive maintenance. The core value is a predictive safety effect achieved through early warning and targeted intervention rather than post-incident mitigation.⁶ For example, continuous machine-condition monitoring (e.g. vibration, acoustic, and thermal signals) could forecast degradation and schedule interventions before breakdowns occur. Unlike fixed-cycle maintenance, predictive approaches identify latent defects that could trigger catastrophic failures, reducing worker exposure to dangerous equipment states and lowering the probability of serious incidents. More recently, systems have increasingly been paired with large language models to translate complex diagnostic signals into actionable messages, enabling machines to “communicate” imminent maintenance needs to human operators and supervisors.⁷

⁶ Campbell Institute (2022). [Serious Injury and Fatality Prevention: Leading Indicators, Cumulative Risk and Safety Networks](#).

⁷ Orviz-Martínez, N., Efrén, P. S. and José Ignacio López-Sánchez, J. I. L. S. (2025). New Trends in the Use of Artificial Intelligence and Natural Language Processing for Occupational Risks Prevention.

- **Algorithmic management and surveillance**

Algorithmic management and surveillance are software systems that automate task allocation and performance monitoring across large or distributed workforces. From a safety perspective, these systems extend oversight beyond the limited reach of safety officers through continuous data tracking and automated decision-making. In industrial settings, a key application links algorithms with computer vision and CCTV systems, turning passive cameras into active monitoring tools that detect leading safety indicators such as unsafe proximity between workers and machinery, PPE non-compliance, and hazardous behaviours. With robust real-time object-detection models, these systems can enable rapid interventions and expand monitoring coverage at a relatively low cost.

- **Visual and wearable safety ecosystems**

Building on visual monitoring, wearable and mobile sensor ecosystems expand situational awareness by capturing data from workers, vehicles, and equipment in motion. Wearables can monitor physiological strain and environmental exposure, while positioning sensors warn operators when unsafe proximity thresholds are breached, helping to reduce struck-by incidents on construction sites. Moreover, these distributed sensors can operate as standalone tools (e.g. simple heart-rate alerts) or be integrated into broader safety systems combining vision, location tracking, and behavioural analytics. Their modular design and relatively low cost make them particularly suitable for higher-risk environments, where even simple interventions can deliver significant safety improvements.

- **Immersive learning and digital twins**

To address training gaps, immersive learning technologies such as VR/AR (virtual reality/augmented reality) and digital twins offer a practical way to scale safety competence. VR/AR training allows workers to rehearse workflows, emergency responses, and hazardous-material procedures in realistic scenarios without the risks or disruptions associated with live production environments. When combined with digital twins (virtual replicas of real assets and workplaces), training can be tailored to specific sites and hazards.⁸ Beyond knowledge transfer, these tools help to build “muscle memory” for correct responses and strengthen situational awareness.⁹

- **Robotics and human-machine collaboration**

Robotics and human-machine collaboration represent another structural shift in industrial safety improvement. Traditional industrial robots operated behind physical cages, whereas collaborative robots (cobots) are designed to share workspaces with humans using force and

⁸ Jeelani, I., Han, K. and Albert, A. (2017). Development of immersive personalized training environment for construction workers. In *Computing in civil engineering*, pp. 407–415.

⁹ Lampropoulos, G., Fernández-Arias, P., Antón-Sancho, Á. and Vergara, D. (2024). Examining the role of augmented reality and virtual reality in safety training. *Electronics*, 13(19): 3952.

torque sensing, compliant materials, and built-in limits on motion and force.¹⁰ Beyond cobots, unmanned systems, such as drones (UAVs), are increasingly used for inspection tasks. These technologies can remove workers from inherently dangerous activities such as climbing structures, inspecting flare stacks, entering confined spaces, or surveying hazardous zones in extractive industries. Equipped with thermal imaging or gas sensors, UAVs enable remote hazard detection while keeping personnel out of high-risk environments.¹¹

¹⁰ Assuring Autonomy International Programme University of York (2019). [Safety assurance of autonomy to support the Fourth Industrial Revolution](#).

¹¹ Singh, A. K., Mohandes, S. R., Muhodir, S. H., Zhang, W., Antwi-Afari, M. F. and Shakor, P. (2025). Exploring Barriers to Unmanned Aerial Vehicle (UAV) Technology for Construction Safety Management Using Mixed-Methods Approach. *Buildings*, 15(12): 2092.

3. Closing the safety tech adoption gap

3.1. Progress in emerging technology adoption for industrial safety

The adoption of technology across industries is critical for enhancing productivity. Emerging technologies, characterised by radical novelty, rapid growth, and prominent impact,¹² are widely expected to drive substantial productivity gains in the coming years.

However, the adoption of emerging technologies specifically to enhance industrial safety has lagged behind other objectives. Evidence suggests that financial motivations, such as revenue growth, cost reduction, and production efficiency, remain the primary drivers of technology adoption in an industrial context.¹³ Moreover, technologies introduced primarily to improve productivity may generate unintended or unforeseen safety consequences if their implications for workspace safety are not adequately assessed.¹⁴

On the other hand, emerging technologies demonstrate considerable potential to improve industrial safety. A study of SMEs participating in UK digital technology adoption programmes found that 26% of survey respondents reported improvements in factory safety or security. Although this share was lower than those reported for benefits such as cost reduction, it highlights the tangible safety gains associated with digital adoption.¹⁵

3.2. Barriers to adopting “safety tech” in an industrial context

Technology developed specifically to improve industrial safety is increasingly referred to as “safety tech”, which is a collection of technology, products, and services designed to enhance workplace safety. Examples of safety tech include exoskeletons, smart sensors, AR and VR applications, wearable devices, drones, and cobots. At the same time, a range of more general-purpose emerging technologies, such as the internet of things (IoT), 5G connectivity, and AI, also have significant implications for improving industrial safety.¹⁶

A growing body of research has examined the barriers to industry adoption of emerging technology solutions, including safety technologies. Although these technologies vary in design and application, common adoption barriers consistently emerge across the literature. Building on existing analysis

¹² Rotolo, D., Hicks, D. and Martin, B. R. (2015). What is an emerging technology? *Research Policy*, 44(10): 1827–1843.

¹³ Lloyd’s Register Foundation (2025). [The impact of emerging technology on safety at work.](#)

¹⁴ Lloyd’s Register Foundation (2025). [The impact of emerging technology on safety at work.](#)

¹⁵ Department for Business and Trade (2024). [Made Smarter Adoption research project.](#)

¹⁶ Lloyd’s Register Foundation (2025). [The impact of emerging technology on safety at work.](#)

frameworks and classifications, such as those used by UK government departments,¹⁷ this report groups these barriers into four interconnected levels: technical, behavioural, organisational, and external environment. Selected examples of these barriers are outlined next:

- **Technical level**

Integration with existing industrial systems is a key technical challenge for the adoption of emerging technologies. To scale deployment from pilot demonstrations to routine operations, industries must ensure that new technologies can operate reliably within existing industrial infrastructure, which often consists of heterogeneous machinery, legacy systems, variable work practices, and non-standard operating conditions. These integration requirements can create technical barriers related to interoperability, data exchange, system compatibility, and adaptation to site-specific processes.¹⁸

Data quality represents another critical barrier to adoption. Uptake becomes uncertain when safety-related data is perceived as noisy, ambiguous, or insufficiently actionable. Ensuring the clarity, reliability, and trustworthiness of collected data is therefore essential for building confidence in safety technologies and supporting sustained use.¹⁹

Infrastructure constraints also pose significant challenges. Restricted internet connectivity, limited device management, and maintenance capabilities could hinder the effective adoption of digital safety tools such as sensors and wearable devices.²⁰

- **Behavioural level**

Across the literature, worker acceptance is consistently identified as a critical factor in the adoption of safety technologies. In particular, greater effort is required when technologies are perceived as instruments of surveillance, sources of additional workload, or threats to worker autonomy.²¹

Privacy concerns are among the most frequently cited barriers, particularly when safety technologies directly interact with workers' bodies or behaviours. For example, in Italian metalworking SMEs, privacy concerns were identified as a key obstacle to the adoption of

¹⁷ Department for Science, Innovation and Technology; Department for Culture, Media and Sport (2025). [Barriers and Enablers to Advanced Technology Adoption for UK Businesses](#).

¹⁸ Cagno, E., Accordini, D., Neri, A., Negri, E. and Macchi, M. (2024). Digital solutions for workplace safety: An empirical study on their adoption in Italian metalworking SMEs. *Safety Science*, 177: 106598

¹⁹ Cagno, E., Accordini, D., Neri, A., Negri, E. and Macchi, M. (2024). Digital solutions for workplace safety: An empirical study on their adoption in Italian metalworking SMEs. *Safety Science*, 177: 106598

²⁰ Dadoo, J. E., Al-Samarraie, H., Alzahrani, A. I., Lonsdale, M. and Alalwan, N. (2024). Digital innovations for occupational safety: Empowering workers in hazardous environments. *Workplace Health & Safety*, 72(3): 84–95.

²¹ Dadoo, J. E., Al-Samarraie, H., Alzahrani, A. I., Lonsdale, M. and Alalwan, N. (2024). Digital innovations for occupational safety: Empowering workers in hazardous environments. *Workplace Health & Safety*, 72(3): 84–95.

digital safety solutions.²² Importantly, privacy concerns can also undermine data completeness and quality. For example, workers may avoid wearing devices properly, disable features, or provide incomplete inputs. This, in turn, affects technical performance and weakens managerial confidence in the system.

Ease of use repeatedly emerges as a driver of adoption. Complex interfaces, intrusive system requirements, and burdensome routines can significantly hinder uptake, even when the underlying technology is technically sound.²³

- **Organisational level**

Limited visibility of potential safety outcomes relative to the associated costs and implementation effort is emerging as a key barrier to the adoption of safety tech. Literature reviews on digital OHS interventions indicate that much of the existing research focuses on technological development, while providing limited evidence of measurable improvements in working conditions or reductions in injuries and illnesses.²⁴

BOX 1 THE EVIDENCE GAP BEHIND SAFETY TECH ADOPTION

Why visibility of safety outcomes matters for safety tech adoption

Compared with financial objectives such as revenue growth, cost reduction, and production efficiency, workplace safety is often a weaker driver of technology adoption. In risk-averse industrial environments, limited and unclear evidence of tangible safety benefits makes decision-makers cautious about investing in safety technologies, often perceiving such investments as a business burden rather than a gain, particularly when costs and implementation efforts are high. At the same time, when the expected safety outcomes are unclear, workers may also lack motivation to change established routines or adopt unfamiliar technologies and products.

The lack of clarity around safety outcomes also makes it more difficult to analyse the ROI for safety-related initiatives. This creates challenges for justifying investments, discussing them across departments, and aligning decisions among different internal stakeholders.

Overall, this evidence gap weakens the business case and reduces top management commitment. Increasing the visibility of credible safety outcomes would therefore represent a critical first step in encouraging pilot projects and building organisational confidence in safety technologies.

²² Cagno, E., Accordini, D., Neri, A., Negri, E. and Macchi, M. (2024). Digital solutions for workplace safety: An empirical study on their adoption in Italian metalworking SMEs. *Safety Science*, 177: 106598

²³ Cagno, E., Accordini, D., Neri, A., Negri, E. and Macchi, M. (2024). Digital solutions for workplace safety: An empirical study on their adoption in Italian metalworking SMEs. *Safety Science*, 177: 106598

²⁴ Trask, C. and Linderoth, H. C. (2023). Digital technologies in construction: A systematic mapping review of evidence for improved occupational health and safety. *Journal of Building Engineering*, 80: 108082.

Source: Lloyd's Register Foundation (2025). [The impact of emerging technology on safety at work](#); the UK government (2025). [Technology Adoption Review](#); Department for Science, Innovation and Technology; Department for Culture, Media and Sport (2025). [Barriers and Enablers to Advanced Technology Adoption for UK Businesses](#); Safetytech Accelerator. [Investing in Emerging Technology in High-Risk Industries A 6-Step Guide for Innovation Leaders](#).

Cost and resource constraints are repeatedly identified as key barriers to adoption, particularly in the context of SMEs and developing countries. For example, high initial implementation costs have been highlighted as one of the primary obstacles to IoT adoption in the Bangladeshi manufacturing sector, where enhanced workplace safety is recognised as a potential benefit.²⁵ Beyond financial investment, resource constraints also encompass organisational capacity, such as the availability of internal champions, IT expertise, time for training and process redesign, and the capability to conduct pilot projects and evaluate outcomes.

Skills gaps are also frequently highlighted in the literature as a significant barrier to adoption. In the context of safety technology, required capabilities extend beyond basic operational proficiency. In addition to knowing how to use new tools, workers and managers need training in interpreting system outputs, understanding data-driven insights, and managing effective human–technology collaboration.²⁶

- **External environment level**

Regulatory pressure can be a positive and a negative. On the one hand, compliance requirements can drive the adoption of safety technologies. And on the other hand, unclear regulatory acceptance, documentation burdens, and concerns about liability if a tool fails may discourage adoption.²⁷

Weak market and client incentives represent another external barrier, particularly in some developing countries.²⁸ As noted by an industrial expert during consultation, one of the key drivers behind Chinese manufacturers' adoption of safety technologies in past decades has been the rising cost of workplace accidents, combined with increasingly stringent regulatory requirements and growing pressure from domestic and international clients.

²⁵ Shahriar, H., Islam, M. S., Jahin, M. A., Ridoy, I. A., Prottoy, R. R., Abid, A. and Mridha, M. F. (2024). Exploring internet of things adoption challenges in manufacturing firms: A Delphi fuzzy analytical hierarchy process approach. *PLOS One*, 19(11): e0311643.

²⁶ Daniel, E. I., Oshodi, O. S., Nwankwo, N., Emuze, F. A. and Chinyio, E. (2024). Barriers to the application of digital technologies in construction health and safety: A systematic review. *Buildings*, 14(8): 2386.

²⁷ Masi, D. and Cagno, E. (2015). Barriers to OHS interventions in small and medium-sized enterprises. *Safety Science*, 71: 226–241.

²⁸ Daniel, E. I., Oshodi, O. S., Nwankwo, N., Emuze, F. A. and Chinyio, E. (2024). Barriers to the application of digital technologies in construction health and safety: A systematic review. *Buildings*, 14(8): 2386.

4. A framework for assessing safety technology effectiveness

4.1. Hazards, risks, and industrial safety

The International Organization for Standardization (ISO) defines OHS risks as arising from the combination of the likelihood of a work-related hazardous event and the severity of the resulting injury or ill health.²⁹ As this definition indicates, OHS risks can be understood as comprising three core elements: (1) hazards, (2) the likelihood of hazardous event occurrence, and (3) the severity of consequences. Hazards are factors with the potential to cause injury or ill health, while hazardous events are the specific harmful incidents or exposures through which injuries or illnesses occur.³⁰

In practice, the likelihood of hazardous events and the severity of their consequences are often considered together and collectively referred to as industrial safety risks.³¹ Accordingly, technology solutions aimed at improving industrial safety can be interpreted in terms of how they address one or more of these elements, including by:

- removing hazards, and/or
- reducing the likelihood of hazardous events, and/or
- lessening the severity of consequences.

In many contexts, the terms “hazard” and “sources of hazards” are used interchangeably. But they are distinct concepts. While hazards are conditions or factors with the potential to cause harm, sources of hazards are the persons or objects that most directly produce injury, such as vehicles, machinery, chemicals, animals, plants, or humans.³²

For the purposes of this report, the removal of hazards refers to eliminating or reducing the conditions or factors that give rise to injury or ill health, rather than necessarily requiring the complete removal of the physical sources of hazards themselves. For example, in addressing OHS risks associated with mechanical noise, hazard removal may involve reducing noise levels through upgraded manufacturing processes or upgrading equipment with noise-reducing features, rather than removing the machinery entirely from the factory floor.

²⁹ ISO (2018). [International Standard ISO 45001 First edition.](#)

³⁰ US Bureau of Labor Statistics (2023). [Occupational Injury and Illness Classification \(OIICS\) Manual.](#)

³¹ ISO (2018). [International Standard ISO 45001 First edition.](#)

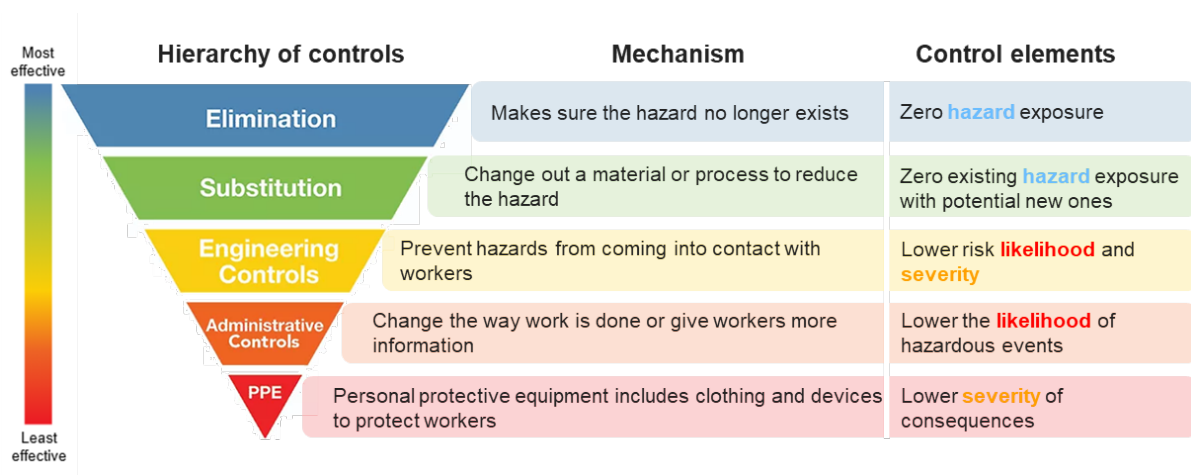
³² US Bureau of Labor Statistics (2023). [Occupational Injury and Illness Classification \(OIICS\) Manual.](#)

4.2. Mechanisms of improving industrial safety

The Hierarchy of Controls developed in the 1950s has become a widely used tool for employers across industries to identify safeguards to improve industrial safety. Ranked by effectiveness from highest to lowest, these safeguards are grouped into five tiers: (1) elimination, (2) substitution, (3) engineering controls, (4) administrative controls, and (5) personal protective equipment (PPE).

Each tier of controls applies different mechanisms to improve industrial safety. Viewed through the lens of the three core elements of industrial safety improvement, including hazards, likelihood of occurrence, and severity of consequences, this sub-section examines how these mechanisms operate and where their primary impact lies. By mapping each tier against the control elements it most directly influences, this analysis explains the differences in the relative effectiveness of the various mechanisms. The results of this discussion and mapping are summarised in Figure 4.

FIGURE 4 MECHANISMS OF THE HIERARCHY OF CONTROLS FOR IMPROVING INDUSTRIAL SAFETY



Source: CIIP adapted from the US Occupational Safety and Health Administration. [Identifying Hazard Control Options: The Hierarchy of Controls.](#)

- Elimination**
 Elimination is the most effective safety mechanism, as it removes hazards entirely and addresses the root source of risk rather than managing its probability or consequences. The objective is to eliminate human exposure to hazards, by removing the hazard from the workplace or by redesigning work processes so that workers are no longer exposed.
- Substitution**
 Substitution is less effective than elimination, although it also targets the hazard itself. This approach involves replacing hazardous materials, equipment, or processes with less harmful alternatives. However, substitution may introduce new or different forms of exposure.
- Engineering controls**
 Engineering controls focus on interrupting the pathway between hazards and workers. By isolating hazards through physical design solutions, engineering controls reduce both the likelihood of hazardous events and the severity of potential consequences.

- **Administrative controls**

Administrative controls operate as an *ex ante* approach by proactively reducing the likelihood of hazardous events. Common measures include warning systems, signage, labelling, instructions, and training programmes developed to influence worker behaviour and work practices.

- **Personal protective equipment**

PPE functions primarily as an *ex post* measure, offering limited mitigation of the severity of consequences once an incident has occurred. Although it is the least effective control tier, PPE remains necessary, particularly when higher-level controls are not feasible.

4.3. Assessing the effectiveness of “safety tech” solutions

As discussed in the previous sections, a growing number of emerging technology solutions, collectively referred to as “safety tech” solutions, are entering the market, with vendors advocating their potential benefits for industrial safety. However, in some cases, these technologies appear to be solutions in search of a problem.

At the same time, limited perceived benefits remain a key barrier to their adoption by industry. Industrial users often feel overwhelmed by the range of available technologies and lack clear visibility of the relative benefits and effectiveness of different options, making cross-comparison difficult. This challenge is compounded by the need to consider the varying costs and resource requirements associated with each option.

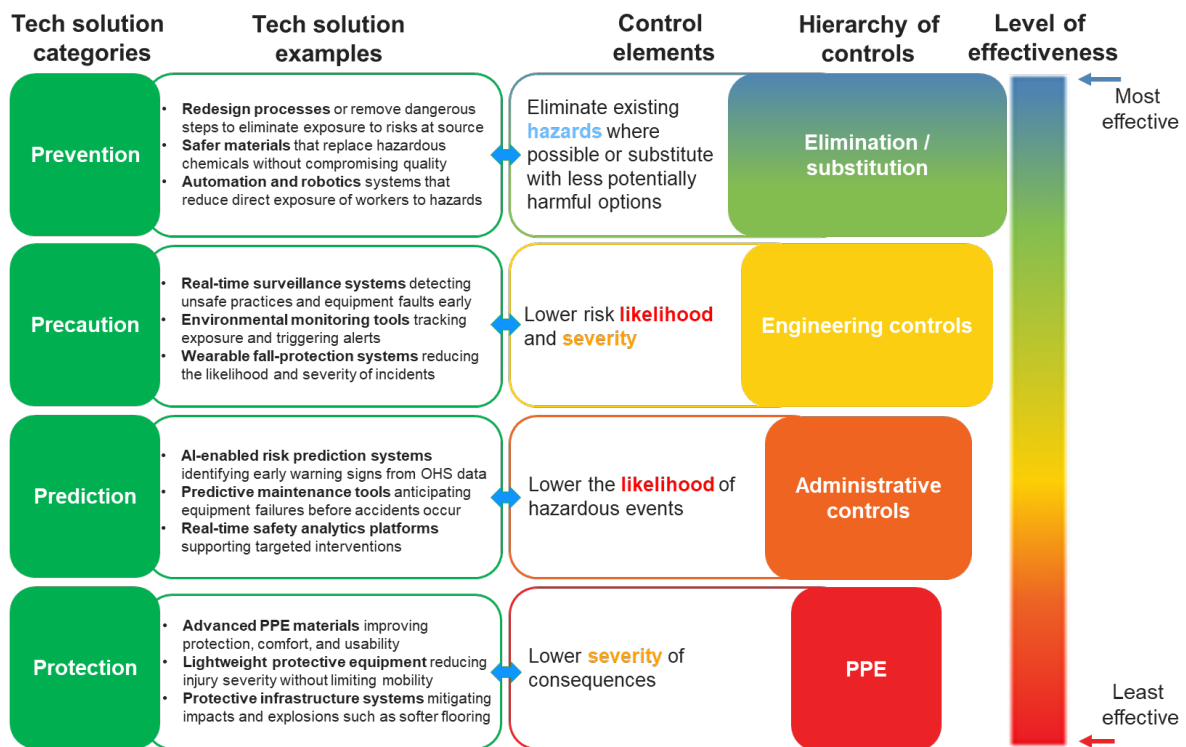
In response, this report proposes a framework to help industrial practitioners evaluate the effectiveness of technology solutions and improve the visibility of their potential safety benefits, while supporting solution providers to clearly articulate their value propositions. Given the breadth of technologies addressing OHS challenges, a structured categorisation is necessary to enable systematic assessment. The categorisation developed in this report builds on the approach adopted in the World Intellectual Property Organization (WIPO) patent landscape analysis on OHS.³³ In the WIPO report, safety technologies are identified according to how they address industrial safety risks, specifically by reducing the likelihood of hazardous events or mitigating the severity of their consequences.

Building on this foundation and applying the lens of the three core elements of industrial safety improvement, this report also considers technologies that directly address hazards per se, such as innovations in materials and operational processes. Accordingly, the proposed framework groups safety technology solutions into four categories: (1) prevention, (2) precaution, (3) prediction, and (4) protection.

³³ WIPO (2025). [Patent Landscape Report - Occupational Health and Safety \(OHS\)](#).

By examining the primary control elements targeted by each technology category, this framework maps the four categories against their relative effectiveness in improving industrial safety. The mapping results are shown in Figure 5, followed by further discussion.

FIGURE 5 A FRAMEWORK FOR ASSESSING THE EFFECTIVENESS OF SAFETY TECH SOLUTIONS



Source: CIIP, adapted from WIPO. [Patent Landscape Report - Occupational Health and Safety \(OHS\)](#).

- **Prevention**

Safety tech solutions in this category are developed to prevent occupational accidents or work-related diseases at their root source by addressing hazards directly, through the complete elimination of hazards or by substituting them with less hazardous alternatives. These solutions focus on removing or fundamentally reducing the presence of harmful conditions within the work environment, minimising workers' exposure to hazards. By targeting hazards per se rather than managing their consequences or likelihood, such solutions are generally considered the most effective means of improving industrial safety.

Common practices include replacing hazardous chemicals with safer materials or redesigning production processes to eliminate dangerous steps. By adopting toxic-free product formulations while maintaining product quality, plastic compound manufacturers can significantly reduce risks to workers handling hazardous chemical materials and lower the need

for ongoing medical monitoring.³⁴ In response to the catastrophic risks associated with storing methyl isocyanate (MIC), DuPont redesigned its methomyl production process to minimise MIC inventory. MIC was generated on demand as a vapour and consumed immediately, eliminating the need for transport and storage of MIC and phosgene.³⁵

In addition to removing hazards from the workspace, replacing human labour with automated machinery or robots is another effective approach to reducing occupational exposure.³⁶ From the use of façade-cleaning robots for high-rise buildings³⁷ to robotic arms for welding,³⁸ industrial robots enhance workspace safety by taking over tasks commonly described as “dirty, dull, and dangerous”.

- **Precaution**

This category includes safety solutions that enable continuous oversight of workplace conditions through real-time surveillance, periodic inspections, and environmental monitoring. These approaches are designed to detect unsafe practices, equipment malfunctions, or harmful exposure levels at an early stage. By maintaining continuous monitoring of operational environments, such technologies can help to identify emerging risks before they escalate into accidents, while providing timely alerts when incidents begin to occur, reducing the severity of potential consequences.

In addition, this category covers technologies that proactively prevent hazardous events or provide protection when incidents occur. Examples include safety harnesses, guardrails, and other protective systems used in environments with fall risks, as well as monitoring tools that ensure compliance with safety procedures. Together, these solutions strengthen workplace safety by addressing the elements of likelihood of hazardous events and the severity of their consequences.

³⁴ US Department of Labor. [Transitioning to Safer Chemicals: A Toolkit for Employers and Workers Success Stories](#).

³⁵ US Department of Labor. [Transitioning to Safer Chemicals: A Toolkit for Employers and Workers Success Stories](#).

³⁶ Gihleb, R., Giuntella, O., Stella, L. and Wang, T. (2022). Industrial robots, workers' safety, and health. *Labour Economics*, 78: 102205.

³⁷ Fraunhofer IFF. [Research and Development in Robotic Systems High-rise Facade Cleaning](#).

³⁸ Robots Done Right. [Spot Welding Robots](#).

Smart harness belt for safer work at height

Falls from height are a major cause of occupational injury and death. Traditional controls often rely on line-of-sight supervision and consistent human vigilance. REMOC's smart harness belt shifts working-at-height safety from periodic "spot checks" to continuous, predictive monitoring, detecting risky conditions early and prompting immediate intervention.

The smart harness belt identifies when high-altitude work is taking place and checks critical behaviours such as hook attachment, hook lock status, and buckle fastening, linking these signals to who is exposed and where the exposure is occurring. When improper use is detected, workers receive on-device audible alerts through built-in speakers, while supervisors and administrators receive dashboard and email notifications, enabling rapid correction, coaching, and follow-up.

The solution has been applied by Nitto Denko (chemical industry) during the construction of an automated warehouse in Shenzhen, China. Over approximately four months of use, the case reported 0 fall accidents and a 92% reduction in fall accident risk, alongside a marked improvement in safe practice: alerts decreased from 26 in the first month to 2 in the final month.

Source: [REMOC INC.](#)

- **Prediction**

This category focuses on the proactive identification and assessment of potential hazards to prevent accidents and incidents before they occur. Leveraging statistical analytics derived from OHS data and enhanced by AI and machine learning, prediction technologies and methodologies detect patterns and early-warning signals associated with hazardous events.

By analysing relevant operational, behavioural, and environmental data, these tools can anticipate the likelihood of accidents at an early stage, enabling organisations to take preventive actions before risks materialise. In addition to supporting real-time risk detection, predictive approaches can inform safety planning, resource allocation, and targeted interventions. As a result, prediction technologies strengthen proactive safety management by enabling more informed and forward-looking decision-making.

Sainsbury's uses predictive risk mapping to prevent safety incidents

Sainsbury's, one of the UK's largest retailers, wanted to move beyond retrospective safety reporting and start spotting where the next problem was likely to happen. Working with Alcumus, it built a predictive software called *Risk Map* to turn scattered safety data into practical early warnings across more than 2,000 locations.

The *Risk Map* pulls together both lagging and leading indicators (e.g. incidents/near misses, claims patterns, audit trends, training completion, food hygiene ratings, colleague opinion signals, regulatory contacts, pest activity, and other operational checks), plus selected HR/finance inputs. The system applies weightings and continuously refreshes scores as new data is imported, creating a near real-time view of emerging risk.

Through a central dashboard, managers in Sainsbury's can quickly see which stores' risk profiles are deteriorating, what factors are driving the change (e.g. training gaps, cleaning/temperature-control issues), and where targeted support is most likely to prevent harm. Based on the information, the managers can prioritise visits "with a purpose", focusing limited safety resources on the highest-risk locations before serious events occur. Over time, this shifted Sainsbury's from "passing audits" to managing risk trajectories, strengthening preventive interventions, improving compliance conversations, and embedding a more proactive safety culture.

Source: British Safety Council (2019). [Technology in action](#); The Retail Bulletin (2021). [\[ON DEMAND\] – Risk Mapping – Challenges and Lessons Learned by Sainsbury's](#).

- **Protection**

The provision of PPE, including helmets, gloves, masks, and protective clothing, falls within this category. As the last line of defence in industrial safety, PPE is primarily intended to lessen the severity of consequences once a hazardous event has occurred, rather than preventing the event itself. PPE therefore plays a critical role in protecting workers from injury when other control measures cannot fully eliminate or mitigate workplace hazards.

Studies have shown that discomfort and poor fit are among the main reasons why workers do not consistently use PPE.³⁹ In response to this challenge, the development of advanced and lightweight protective materials has gained increasing attention. Technologies such as nanotechnology have played a significant role in this transition, enabling new materials that

³⁹ Sehsah, R., El-Gilany, A. H. and Ibrahim, A. M. (2020). Personal protective equipment (PPE) use and its relation to accidents among construction workers. *La Medicina del Lavoro*, 111(4): 285.

enhance comfort and usability while maintaining, or even improving, resistance to hazardous substances.⁴⁰

Taken together, the “4Ps framework for safety technology solutions” (prevention, precaution, prediction, and protection) is an actionable tool for understanding the effectiveness of different technologies improving industrial safety. Their boundaries are not always fixed, and some technologies may span multiple categories. For example, digitally enabled wearables may function both as PPE and as monitoring tools. The framework should therefore be seen as a starting point for analysis rather than a rigid classification. Its value lies in helping industrial practitioners to assess and compare safety technology options more systematically, in terms of not only relative effectiveness but also cost, implementation effort, and resource requirements. In turn, this can support more informed decisions on technology adoption.

4.4. A case study: technology solutions for fall-from-height risks

Falls from height are one of the main causes of work-related deaths across industries worldwide. In 2016 more than 34,000 fatalities were attributed to falls from height globally.⁴¹ In the European Union, there were 584,371 workplace accidents in 2019 due to slips, trips, and falls, of which 520 were fatal.⁴² In the United Kingdom, more than 5,000 workers were injured as a result of falls from height in 2022/23, with 40 fatalities,⁴³ resulting in an estimated total cost exceeding £847 million.⁴⁴

Construction and manufacturing are among the sectors most affected by the risk of falls from height. For example, in South Korea’s construction industry, 26,486 injuries were reported in 2018, of which 34.7% (9,191 cases) were due to falls, the highest proportion among all accident types. Similarly, in Japan in 2022, falls from height accounted for 32% (4,594 cases) of 14,539 accidents in construction, and 11% (2,867 cases) of 26,694 accidents in manufacturing.⁴⁵

Technology solutions addressing the industrial risk of falls from height are well developed. WIPO’s *Patent Landscape Report: Occupational Health and Safety*, published in 2025, identifies more than 19,000 patented technologies between 2004 and 2024 specifically related to fall protection.⁴⁶ Building on this evidence, a background study⁴⁷ published by GIFIS analyses these patents to examine overall trends over the past 2 decades, including technology focus areas and applications across industries.

⁴⁰ HSE Network (2023). [Tech Trends: How Technology is Shaping the Future of PPE](#).

⁴¹ WHO and ILO (2021). [WHO/ILO joint estimates of the work-related burden of disease and injury, 2000-2016: global monitoring report](#).

⁴² IOSH. [Working at height: don’t fall silent](#).

⁴³ British Safety Council (2024). [Simplified reporting of falls from height will identify ways to prevent accidents](#).

⁴⁴ IOSH. [Working at height: don’t fall silent](#).

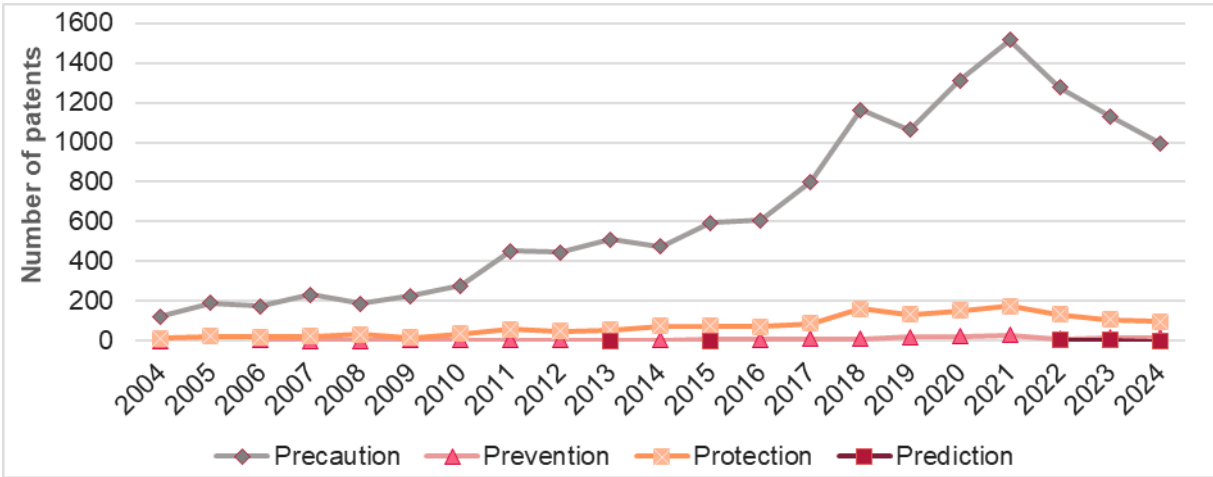
⁴⁵ IOSH. [Working at height: don’t fall silent](#).

⁴⁶ WIPO (2025). *Patent Landscape Report: Occupational Health and Safety*. Geneva: WIPO.

⁴⁷ GIFIS (forthcoming). Preventing the Fall Global Innovation in Fall-From-Height Safety Technologies.

Referring to the 4Ps framework for safety tech solutions proposed in this report, the study classifies these 19,000 patents into 4 technology solution categories: prevention, precaution, prediction, and protection. Patent trends across the four categories between 2004 and 2024 are presented in Figure 6. As demonstrated in the study, the 4Ps framework is an effective tool for systematically classifying and reviewing diverse safety tech solutions.

FIGURE 6 TRENDS IN FALL-FROM-HEIGHT PATENTS BY TECHNOLOGY CATEGORY



Source: Lens.com, WIPO.

Several key insights could be drawn from the Expert Input report⁴⁸ by applying the 4Ps framework:

- Over the past 2 decades, annual patent applications for technologies addressing falls from height have increased significantly, rising from fewer than 200 applications in the early 2000s to nearly 1,800 in the 2020s. Within this overall growth trend, technologies in the precaution category have led the increase. These include fall-arrest systems, scaffolds, ladders, working platforms, and guardrails.
- The technological focus is gradually shifting from traditional mechanical equipment, such as scaffolds and ladders, to digitally enabled devices and systems. In particular, smart devices with monitoring/detection functions have experienced the most rapid growth in recent years. While the absolute number of prevention technologies (e.g. robotics and remote inspection systems) remains lower, these solutions have shown strong growth momentum.
- China and South Korea lead the adoption and development of technology solutions for fall-from-height risks, particularly in integrating digital technologies. In contrast, many European

⁴⁸ GIFIS (forthcoming). Preventing the Fall Global Innovation in Fall-From-Height Safety Technologies.

countries and Japan continue to focus on traditional mechanical and physical safety equipment, such as safety harnesses and barriers.

- Construction and manufacturing are the industries with the highest adoption of technology solutions addressing falls from height, compared with sectors such as mining and logistics. At the same time, medical equipment and patient handling systems show the strongest uptake of digitally enabled devices and systems. However, these applications are less directly relevant to industrial settings, highlighting potential opportunities to transfer digital innovations into industrial safety contexts.

5. Conclusions

This white paper has shown that industrial safety is increasingly shaped by both persistent global challenges and rapid technological change. While work-related deaths and injuries continue to impose a major human and economic burden, emerging technologies offer significant potential to identify hazards earlier, strengthen prevention, and reduce exposure to dangerous conditions.

However, the adoption of safety technologies remains constrained by an increasingly crowded market, while industrial users often have limited visibility of the safety outcomes these technologies can deliver. This mismatch makes it difficult for practitioners to compare options, build a convincing business case, and make informed decisions about adoption.

Against this backdrop, the framework proposed in this report provides an actionable tool to assess the effectiveness of different safety technology options. By connecting technologies to the core elements of industrial safety improvement, including hazards, likelihood of occurrence, and severity of consequences, it helps industrial practitioners to compare solutions more systematically and understand where each technology may create the greatest safety value.

Importantly, the framework is not only a tool for clarifying effectiveness. It also creates a foundation for further analysis of costs, resource requirements, and potential return on investment, helping practitioners move towards grounded and actionable adoption decisions. By making the expected safety impact of different technologies more explicit, the framework helps organisations to prioritise investments based on not just technical capability but feasibility, scalability, and alignment with operational constraints. In practice, this means supporting more robust business cases for safety tech adoption – linking upfront costs and implementation effort (e.g. integration with existing systems, workforce training, and change management) with anticipated reductions in incidents, downtime, and liability. It also allows for more meaningful comparisons across technology options, including trade-offs between higher-impact but more complex solutions and simpler, lower-cost interventions.

Looking ahead, further work should focus on strengthening the evidence base underpinning the effectiveness of different safety technologies, particularly through real-world implementation data and cross-sector benchmarking. There is also a need to better integrate cost–benefit considerations, including life-cycle costs and organisational readiness, into decision-making frameworks. In parallel, future research could explore how combinations of technologies, rather than individual solutions, interact to deliver system-level safety improvements. Finally, continued collaboration between industry, technology providers, and the broader safety community will be essential to refine these approaches, share learning, and accelerate the adoption of solutions that demonstrably reduce harm.



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