INTERNATIONAL CONFERENCE ON

Ensuring **Industrial Safety**

The role of government, regulations, standards and new technologies

UNIDO

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International Conference on Ensuring Industrial Safety

The role of government, regulations, standards and new technologies

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ABBREVIATIONS

IAEA	International Atomic Energy Agency
ILO	International Labour Organization
ISO	International Organization for Standardization
LDCs	Least developed countries
OHS	Occupational health and safety
OSHA	Occupational Safety and Health Administration (United States)
SDGs	Sustainable Development Goals
SMEs	Small and medium-sized enterprises
UNDRR	United Nations Office for Disaster Risk Reduction
UNECE	United Nations Economic Commission for Europe
UNIDO	United Nations Industrial Development Organization
UNISDR	United Nations Office for Disaster Risk Reduction
UNODC	United Nations Office on Drugs and Crime
UNOOSA	United Nations Office for Outer Space Affairs
WHO	World Health Organization

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FOREWORD BY LI YONG, DIRECTOR GENERAL, UNIDO

Industrial safety is often an overlooked attribute of well-being that is important for achieving the 2030 Agenda for Sustainable Development and its associated Sustainable Development Goals (SDGs). Industrial processes, equipment and factories have the potential to create hazards that can harm individuals, the environment and industrial assets.

At the same time, natural hazards, political instability, sabotage and cybercrime can cause massive damage to entities of the industrial sector. These natural and human-caused hazards can affect the social, economic and environmental pillars of sustainable economic development. When governments and companies alike ignore industrial safety, along with the prospects of damage from climate change, that neglect will be reflected in lower productivity, competitiveness and resilience, posing a serious threat to realization of Agenda 2030 and the SDGs.

Because industrial activities will never be entirely free of risk from natural and human-caused hazards, it is essential to understand these risks as thoroughly as possible to inform supervisory authorities and to take suitable risk-mitigation measures based on best practices and best available technologies.

Machines are increasingly connected with industrial processes and perform tasks in cooperation with humans. Early automation and mass production have brought many challenges and, moving forward, technological solutions of the new industrial revolution will create new challenges for industrial safety. Machines, technical equipment and buildings can have shortcomings and, as such, they need to be designed with harm reduction in mind. In addition to these precautionary steps to ensure the safety of workers and the environment, there is also a need to consider security. Machines can be deliberately exploited for nefarious purposes—for instance, during cyberattacks—and that possibility should be taken into account when implementing or redesigning production systems.

Developing countries, especially the least developed countries (LDCs), are more vulnerable to hazards at industrial sites than developed countries. We can attribute this to a number of factors, such as a lack of safety standards and compliance, poor land planning and, in general, a low degree of safety awareness, education and training.

In many developing countries and LDCs, industrial facilities are commonly built on inappropriate geographic sites, making them dangerously susceptible to natural hazards. Natural hazards can occur virtually anywhere, but some locations are more vulnerable than others since they are more prone to floods, earthquakes and other extreme events that call for special measures. And climate change will exacerbate the economic damage stemming from natural disasters. Therefore, mapping hazardous industrial sites and zones, as well as coordinating land use policy with industrial safety policy, is of growing importance. Challenges some countries face from natural disasters, such as repeated flooding in industrial areas, can be avoided if sound safety frameworks that clearly indicate the minimum requirements for industrial activities are executed.

But beyond these environmental factors, some industries are intrinsically more hazardous than others. These include oil and gas, chemical, construction, and mining industries, among many others. Therefore, industrial safety considerations require closely examining the hazardous working environments in individual industries and the specific safety measures needed. Improper operations, handling or over-exploitation of industrial resources are safety concerns that require close examination. Mining is a prime example of an industry where these factors can lead to catastrophes, such as the collapse of mines, causing human, material and environmental damage. The need to deal with these concerns is amplified by the existence of transboundary spillover effects. Many industrial safety and security concerns can be solved by installing occupational health and safety mechanisms and by providing adequate industrial safety training for workers.

To ensure meaningful environmental protection and to address potential industrial risks, accidents and hazards, collective action is imperative at the international level as well as the national level. At the international level, protocols, conventions and agreements have been used to manage the negative impacts of industrial accidents. Partnerships among companies, civil society and government agencies are also critical to share vital information and ensure a commitment to common goals.

The cooperation between UNIDO and Rostechnadzor (Russian Federal Environmental, Industrial, and Nuclear Supervision Service) at the International Conference on Ensuring Industrial Safety, held in Vienna at the end of May 2019, is an example of investing in continuing efforts to achieve industrial safety in all countries, so that no one is left behind. The conference was the first major activity undertaken by the two parties since their commitment to cooperate on strengthening industrial safety and security on a global level. It brought together government officials from ministries, institutions and committees that are responsible for ensuring industrial safety; representatives of international organizations (including the International Atomic Energy Agency, International Labour Organization, United Nations Economic Commission for Europe, United Nations Office for Disaster Risk Reduction, United Nations Office on Drugs and Crime, and United Nations Office for Outer Space Affairs); and representatives from academia and the private sector.

By sharing knowledge and experiences, innovative approaches and technological solutions, we can help each other secure industrial safety globally. This report is a crucial step in that direction.

1

UNDERSTANDING INDUSTRIAL SAFETY AND SECURITY

Raising awareness about industrial safety, in particular occupational health and safety (OHS), at the local (firm), national, regional and international levels is the first step towards achieving it.[1] Many firms and national governments, even those in industrially developed regions, are either unaware of the vital importance of industrial safety or tend to ignore it.

Although 70 percent of surveyed members of the International Commission on Occupational Health from 47 industrialized and industrializing countries reported that OHS standards were in place in their country and 80 percent confirmed having a national institute for OHS, only an estimated 19 percent of workers were covered by OHS services.[2] The situation is worse in developing countries and the least developed countries (LDCs). Only 10 percent of the population in these countries is covered by OHS laws, with the exception of some major hazardous industries and occupations.[3] Moreover, many small and medium-sized enterprises (SMEs) do not meet the OHS standards and guidelines set by the International Labour Organization (ILO) and the World Health Organization (WHO).[4] It is thus a global imperative to systematically raise awareness about industrial safety and its growing pertinence.

1.1. What is industrial safety?

Industrial safety encompasses the prevention of a wide variety of industrial hazards, occupational accidents and work-related illnesses in order to create a "zero-risk" environment. While this is a challenging task, effective prevention strategies at the enterprise, national, regional and international levels can eliminate, or at least minimize, the occurrence and impacts of industrial hazards. Industrial safety mechanisms should begin at the firm level and expand to industrial sectors, national regulatory systems, regional monitoring entities and international organizations promoting industrial development.

> "The field of industrial safety establishes legal, economic and social principles to ensure the safe operation of hazardous production facilities for the protection of people, the environment and industrial assets."

At the firm level, industrial safety mechanisms refer to the management of all conditions, operations and events within an industrial plant or industrial site to reduce, control and eliminate hazards and protect people, productive assets and the environment. Focused on accident prevention and the safety readiness of the entities operating these facilities, industrial safety provides the means to contain and eliminate accidents and their consequences.

Though industrial activities will never be entirely risk free, it is essential to map associated risks as thoroughly as possible and take suitable mitigation measures based on best practices and innovative technologies. Coordination between standards-setting agencies and monitoring entities, along with partnerships with international organizations supporting industrial development (Figure 1.1), are the key elements for ensuring industrial safety at the national, regional and international levels.

FIGURE 1.1
International Conference on Ensuring Industrial Safety, Vienna 2019

Source: International Conference on Ensuring Industrial Safety, Vienna, 2019.

FIGURE 1.2
Global estimates of mortality from occupational accidents and work-related illnesses in 2014

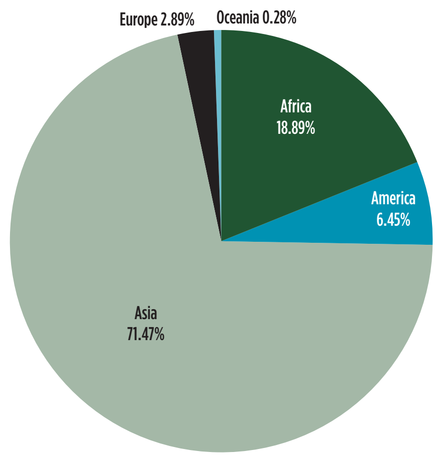
Source: ILO (2019).

Industrial hazards, occupational accidents and work-related illnesses may originate in technological or industrial conditions, dangerous procedures, infrastructure failures or specific human activities.[5] They have a major impact not only on workers, but also on their families and society at large, in both the short and the long run, through injury or loss of life, deterioration in physical and emotional well-being, social and economic disruption, property damage and environmental degradation.[6] Furthermore, such hazards can reduce the productivity and efficiency of enterprises, potentially disrupting production, hampering competitiveness and diminishing the reputation of enterprises along supply chains, affecting the economy and society more widely.[7]

According to the ILO, more than 6,500 people around the world die every day of work-related illnesses and over 1,000 people a day from occupational accidents (Figure 1.2).[8] The number of annual work-related deaths rose from 2.33 million in 2014 to 2.78 million in 2017.[9] Of the 2.78 million work-related deaths in 2017, 2.4 million were associated with occupational diseases.[10] Fatal occupational accidents were highest in Asia, at 71.5 percent in 2014, followed by Africa (18.9 percent), America (6.5 percent) and Europe (2.9 percent; Figure 1.3).[11] The accident fatality rate per 100,000 persons was highest in Africa (17.4) and Asia (13.0), reflecting the global distribution of the working population and hazardous work, as well as differing levels of economic development.

Financial losses due to workplace hazards, illness or injury total almost 4 percent of the world's annual GDP, rising as high as 6 percent or more in

FIGURE 1.3
Global estimates of fatal occupational accidents across regions in 2014



Source: Hämäläinen et al. (2017); ILO (2019).

some countries.[12] These losses include the direct and indirect costs of reconstruction, recovery and reconversion of industrial sites; restoration of ecosystems; production interruptions; lost working time; workers' compensation payments; absenteeism; early retirement; loss of skilled workers; medical expenses; high insurance premiums; and training and rehabilitation. Apart from these economic costs, there are the intangible costs arising from the immense human emotional and physical suffering and work-related stress for individual workers and their families. The environmental impacts of industrial hazards do not recognize borders, and their repercussions spread from local to national, regional and international levels.

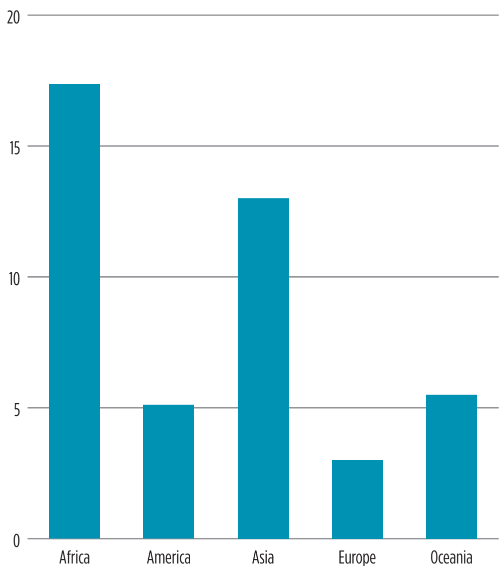
Industrial processes are exposed to dangers such as natural hazards, political instability (sabotage) and cyberattacks. These can cause massive damage to people, industrial assets and the environment. Beyond process, production and material safety, industrial safety is also related to:[13]

- Occupational health and safety.
- Workplace safety.
- Technical equipment safety related to electrical safety and fire safety.
- Cybersecurity.
- Safety in general, including installations following existing building codes.
- Building and structural safety.
- Environmental safety as a direct or indirect impact of industry.

Industrial accidents can be classified according to the source of risk. These hazards include physical (wet floors, loose electrical cables); chemical (production, transportation or handling of hazardous chemical substances); biological (infectious diseases or allergic responses common in health, agro and food processing industries); environmental (air, water and noise pollution; acid rain and temperatures at production facilities); ergonomic (lifting heavy objects, poor desk seating); psychological (use of industrial equipment, heights, industrial noise, bright lights); and radiation (nuclear exposure, exposure to sunlight).[14]

FIGURE 1.4

Global estimates of accident fatality rates in the labour force, by region, 2014 (per 100,000 persons)



Source: Hämäläinen et al. (2017); ILO (2019).

> "Workers' health and safety concerns are the most important aspects of industrial safety."

Accident risk varies across industries and is related primarily to production processes at the industrial site, including materials used and rate of activity. Hazard risks are greater in industries such as chemical processing and oil and gas refining, which have multiple processes spread across land-based facilities (fixed facilities such as chemical establishments, oil terminals and tailings management facilities[15]); pipelines and transport by rail, road and water; and offshore oil exploration platforms.[16]

Industries that manufacture or store explosives, such pyrotechnical plants, also have high rates of industrial accident risk. The mining industry, which uses dangerous substances such as cyanide and arsenic in metals processing, is also at high risk for industrial accidents (Figures 1.5 and 1.6). Industries such as food production, power plants and metal plating also use large quantities of dangerous substances in refrigeration, fuel, metal treatment and other specialized processes.

FIGURE 1.5
Mining dam collapse in Samarco, Brazil, in 2015

Source: The Guardian (2016).

FIGURE 1.6
Zinc spill in Ridder, Kazakhstan, in 2016

Source: The Siberian Times (2016).

Managing risk in these downstream industries is particularly challenging because awareness of the danger of the materials may be lower than in industries whose core business involves the mining, manufacture, storage or handling of highly regulated substances.[17]

How close an industry comes to achieving a zero-risk environment depends on the industry's and society's perception of risk. Awareness of the importance of industrial safety—within enterprises, industries and society—is the first step to realizing a risk-free environment. Awareness leads to alertness, preparedness and timely response (Figure 1.7). Preparedness relies on the technological capacity to prevent or deal with industrial accidents, and timely response counts on having monitoring and regulatory mechanisms in place, both in firms and at the local and national levels. A society sets its goals for attaining a safe and secure industrial environment based on its economic, technological, legal and social capacities. Therefore, the degree of risk reduction often corresponds to the level of technological sophistication and legal capabilities in countries and industrial facilities alike.

FIGURE 1.7
Management of industrial hazards

Source: UNDRR (2019).

1.2. Industrial safety and the 2030 Agenda for Sustainable Development

The basis of stability and prosperity for most countries is inclusive and sustainable industrial development. Vital national interests demand the protection of individuals, society and the state from natural and human-caused disasters. Ensuring industrial safety and security is crucial for inclusive and sustainable industrial development and plays a decisive role in effectively and efficiently achieving the SDGs and the 2030 Agenda for Sustainable Development (Figure 1.8 and Table 1.1).[18]

> "People and the environment should be the focus of industrial safety."

The environmental effects of human economic activity have increased the risk of accidents that endanger people and their livelihoods. Ignoring industrial safety and security, and the risk arising from climate change, can lead to lower productivity, competitiveness and resilience, making the 2030 Agenda and the SDGs less attainable. Pursuing industrial safety and security and mitigating related risks, to the contrary, can yield economic, social and environmental benefits that can enable countries to achieve the 2030 Agenda. A list of SDG targets relevant for achieving industrial safety and security can be found in Appendix 6.1.

1.3. Challenges and the need for cooperation

Industrial safety is neglected in many parts of the world. As a consequence, incidents at industrial facilities often escalate to accidents (for example, because of abuse of processes or failure or damage to technical devices used in the production of hazardous materials). The likelihood of an incident becoming an accident depends on advance preparations and the ability of operators of hazardous production facilities to recognize risks and implement industrial safety measures.

FIGURE 1.8
Industrial safety and the Sustainable Development Goals

Source: Bernardo Calzadilla, UNIDO, International Conference on Ensuring Industrial Safety, Vienna, 2019.

Industrial accident rates are especially high in developing countries and the LDCs. Contributing factors are the poor technical condition of equipment, disregard or lack of knowledge of safe operation guidelines, poor organization and work procedures, inadequate repair or prolonged downtime of machinery, and low qualifications of maintenance staff. These factors are a result of deficient laws and weak compliance with industrial safety requirements and inadequate financial resources for mitigating and containing industrial incidents and accidents. Strengthening industrial safety reduces these risks, boosts growth in industrial sectors and reduces production losses due to incidents or accidents.

Industrial accidents harm not only individuals and industrial assets, but also communities, including those affected by transboundary effects. Negative spillovers from accidents in industrial plants can have cross-border spillover effects that necessitate collective action at national and international levels, in setting norms, standards and regulations.

TABLE 1.1

Relation between Sustainable Development Goals and industrial safety

Sustainable Development Goal	Relation to the achievement of industrial safety and security
3 GOOD HEALTH AND WELL-BEING	Good health is an essential component of industrial safety. By ensuring that workers have safe working conditions and access to health services, companies support healthier staff and better relationships, and also improve productivity.
4 QUALITY EDUCATION	Quality education implies better skills and capabilities to create a safer environment and to respond promptly to physical and psychological safety situations concerning oneself and one's co-workers. Developing countries, especially the least developed countries (LDCs), are more vulnerable to hazards at industrial sites than developed countries because of lack of safety standards and compliance, poor land planning and a low degree of safety awareness, education and training.
5 GENDER EQUALITY	Participation of women in decision-making is important to ensure that safety reaches all. Recognizing diversity, including gender differences, in the workforce is vital in order to ensure the safety and security of all workers.
6 CLEAN WATER AND SANITATION	Widespread water pollution results from accidental releases of hazardous substances, such as accidents at tailings management facilities. To ensure clean water and sanitation, it is crucial to adhere to industrial safety and security standards already in place, and to adjust standards to the changing environment as necessary.
8 DECENT WORK AND ECONOMIC GROWTH	By ensuring occupational health and safety standards, a decent work environment for everyone can be guaranteed. Moreover, a reduction in occupational accidents and work-related diseases can contribute to a more inclusive as well as productive society.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Ignoring industrial safety will be reflected in lower productivity, competitiveness and resilience. Early automation and mass production brought many challenges for industrial safety, and moving forward, the technological solutions of the new industrial revolution will create new challenges for industrial safety. Infrastructure failures may also produce industrial hazards, occupational accidents and work-related illnesses.
11 SUSTAINABLE CITIES AND COMMUNITIES	Ensuring the quality of air, land, water and infrastructure through attention to industrial safety is key to sustainable cities and communities. Machines, technical equipment and buildings need to be designed to ensure the safety of people, workers and the environment.
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Industrial waste management is a crucial component of industrial safety. Industrial safety and security need to be realized in order to guarantee responsible consumption and production.
13 CLIMATE ACTION	Technological accidents triggered by natural hazards are on the rise as a consequence of increasingly extreme weather events, so industrial safety and security standards must steadily adjust to changing conditions.
14 LIFE BELOW WATER	Widespread water pollution is jeopardizing life below water as well as human health. Marine pollution can be minimized by ensuring industrial safety.
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Political instability (sabotage) and cyberattacks can cause massive damage to people, industrial assets and the environment, with transboundary spillover effects, threatening peace and stability. In a world with differing safety standards, inter-institutional coordination is prerequisite for coherent policy- making in industrial safety.
17 PARTNERSHIPS FOR THE GOALS	International coordination and partnerships are required for the transfer of technology that can reduce industrial risks. Statistical capacity building in industrial safety through regular reporting and recording of information is crucial for monitoring and regulating industrial hazards.

Source: UNIDO United Nations https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals.

International coordination is essential to provide countries with best practice examples of how to detect, map, regulate, monitor and mitigate threats to industrial safety and security. A broader platform is needed to develop and disseminate innovative technologies and approaches promoting OHS practices through awareness raising and research.[19] Global platforms that enable international cooperation and networking by all stakeholders expedite knowledge transfer and broker technology transfer and the joint identification of priority areas for policy-makers. So that no one is left behind, any strategy for improving industrial safety should foster cooperation and innovation.

Challenges facing enterprises, governments, regulatory bodies and the international community

Enterprises, governments, regulatory bodies and the international community need to overcome several barriers to ensure industrial safety and security. At the enterprise level, these barriers include:

- Lack of awareness of the risks and costs of industrial accidents.
- Inadequate communication mechanisms related to industrial risk management (prevention, preparedness and response).
- Absence of organizational support and leadership in risk management to ensure industrial safety.
- Lack of a comprehensive strategy for achieving industrial safety and security that can be implemented at the operational and management levels., especially for small and medium-sized enterprises (SMEs) in developing countries and least developed countries.
- Inadequate infrastructure and safety equipment, such as personal protection equipment, particularly in SMEs.
- A focus on the short term and the failure to recognize the long-term profitability made possible through investments in industrial safety and security infrastructure.
- Complacency in maintaining industrial safety standards and norms; loss of focus on risk assessment and management or organizational drift.[20]
- Disregard for local and national regulatory mechanisms that ensure safety and security.
- Failure to identify emerging issues in accident prevention, preparedness and response (such as cybersecurity issues and human-robot coordination, ageing of installations, outdated inspection systems).
- Inadequate reporting mechanisms in firms and infrequent inspections of industrial sites.
- Inattention to broader occupational health and safety issues, such as work stress and anxiety.

To strengthen coordination at the national level, governments need to:

- Craft dedicated disaster prevention and preparedness programmes and protocols.[21]
- Reinforce recovery and reconversion mechanisms and activities at industrial facilities for timely response to minimize consequences of industrial hazards.
- Make industrial safety and security a political priority, and raise awareness at higher policy levels regarding the risks and consequences of industrial hazards.[22]
- Address industrial accidents in a comprehensive and integrated way at the community, municipal, regional, national and international levels, and coordinate cross-border measures.[23]
- Address natural hazards that can trigger technological accidents, in particular through technical guidance on risk assessment.[24]
- Support private sector involvement in policy-making for accident prevention, preparedness and response.
- Examine past industrial accidents and near-misses to draw lessons.[25]

Monitoring and regulatory bodies need to take several steps to deal with regulatory challenges:

- Require regular reporting by enterprises to generate adequate data on industrial accidents and hazards.[26]

- In addition to focusing on hazards that result in loss of life and property, boost the visibility of industrial hazards that cause social disruption, such as evacuation, rehabilitation, environmental damage, loss of jobs and exposure to health risks. [27]

- Increase the frequency of inspections at industrial sites, and provide feedback to firms.

- Seek innovative ways to deal with the increasing complexity of industrial accidents due to human–machine interactions that are often difficult to monitor without the installation of cyber-technologies such as sensors and artificial intelligence.

Innovative partnerships and international cooperation are crucial to attain industrial safety and security. The international community faces several challenges in addressing industrial safety concerns:

- Manage risk across boundaries.

- Ensure compliance with international conventions and protocols on industrial hazards.

- Raise awareness of new industrial risk assessment methodologies and risk management strategies, such as those that incorporate responses to technological accidents triggered by natural hazards and hazards arising from new industrial technologies, in both firms and national regulatory entities, especially in developing countries and the LDCs.

- Promote coordination among national regulatory bodies on regulations, norms and standards on industrial safety.

The promise of new digital technologies

As elaborated in Chapter 5, advanced digital technologies emerging from the fourth industrial revolution-4IR, or Industry 4.0, such as big data, cloud computing, industrial artificial intelligence, industrial internet of things, robotics and 3D printing, are changing the nature of manufacturing and are creating opportunities and challenges for ensuring industrial safety.

The 4IR makes it possible to gather and process data, and act in real time, since devices can be embedded in equipment to detect and report operator behaviour posing a risk to safety. Intelligent cameras can gather digital images or footage and forward them to a central control point, automatically highlighting abnormal behaviour, such as entry into a restricted area, and triggering a response. Many 4IR technologies have safety features built into them.

At the same time, ensuring cybersecurity has become more urgent. Smart manufacturing systems empowered by 4IR technologies are becoming more vulnerable to cyber threats and attacks. Many of the technological innovations installed in industrial sites are connected to the internet and become more vulnerable to cyberattacks on critical infrastructure and to information technology–related disruptions. The complexity of these new technological systems and the heightened risk of intrusion could result in substantial harm to production and even to the health of industrial personnel. Security threats to data, intellectual property risks from cyber-espionage, and cyber-terrorism threats from state and non-state actors are real and present. Security layers and secure computer coding systems are needed to reduce the vulnerability of industrial systems. New approaches are needed to realize the potential of Industry 4.0 technologies to improve industrial safety. Industry 4.0 is advancing at a rapid pace, and international organizations, governments, regulators and standard-setting bodies need to work collectively at a comparable pace to harness the benefits of these new technologies and ensure their safe and secure operation, to reduce any harm to individuals, the environment and industrial assets.

2

STRENGTHENING GOVERNANCE IN INDUSTRIAL SAFETY

The aim of governance in industrial safety is to enhance protection of the vital interests of the individual, society and state against industrial accidents and to minimize their consequences. Governance encompasses the laws, regulations, standards, norms, safety management systems and mechanisms of their implementation that work together to support industrial safety.

Governance requires continual adjustment as circumstances can change with adoption of new technologies and the rising complexity in the lifecycle of a hazardous production facility.[28] To be effective, industrial safety governance requires competence in governing authorities, the scientific community and industry.

2.1. Laws and regulations on industrial safety

Industrial safety is being regulated on many fronts: at the international, national and regional levels. At the international level, ILO Convention 155 – Occupational Safety and Health Convention (1981) provides the framework for international occupational health and safety regulation. The convention which has been ratified by 52 countries is intended to apply to all branches of economic activity and all workers within those branches of economic activity. It requires Member States to develop a coherent national policy and set of laws aimed at preventing accidents and injury to health "arising out of, linked with or occurring in the course of work, by minimising, so far as is reasonably practicable, the causes of hazards inherent in the working environment". Crucially, it does not address transboundary issues.

At the national level, legislation and policies address industrial accident prevention, preparedness and response, occupational safety and health, and so on. At the regional level, there are mandatory regulations, such as the EU Seveso Directive. The UNECE Convention on the Transboundary Effects of Industrial Accidents fosters industrial safety governance and transboundary cooperation for its Parties in the pan-European region. Likewise, through the UN Sendai Framework for Disaster Risk Reduction, United Nations Member States have committed themselves to take measures to foster technological disaster risk management.

However, the current technological revolution present challenges to existing international governance and regulatory frameworks for industrial safety. Developments in technology have brought about new work arrangements that transcend jurisdictional boundaries. While there is an industrial safety convention addressing transboundary issues at the supra-national/regional level (UNECE Convention on the Transboundary Effects of Industrial Accidents), such a convention is absent on a global level.

With functional and geographical fragmentation of production activities mediated by global value chains, companies are producing goods and providing services using labour, production and facilities across multiple jurisdictions. This has led to a de-coupling of decision-making and risk, presenting a challenge to the governance of industrial safety, and is making it difficult to identify which jurisdiction's laws apply in the event of an accident. The transboundary nature of the risks to industrial safety and security require a rethinking of how to regulate OHS and deal with accountability on a global stage.[29] Moreover, government agencies often lack sufficient institutional capacity to implement, monitor and enforce compliance with industrial safety regulations. Enhanced industrial safety governance needs to be dynamic and flexible enough to face existing and emerging challenges.[30]

In industrialized countries, a strong safety record is based on continuous adjustments and improvements in regulatory systems. Legal and policy mechanisms in the European Union, the United States and the Russian Federation, among others, make it possible to raise awareness about and ensure adherence to safety requirements, environmental protection and public health. While these important features of industrial safety regulation differ among international counterparts, they are all critical for ensuring industrial safety.

The European Union, for instance, has an extensive industrial safety framework that sets voluntary guidelines and standardization principles that provide technical specifications for industrial products, services and process safety. These specifications cover issues ranging from safety helmets to chargers for electronic devices to service quality levels in public transport. Although implementation is voluntary, this framework establishes uniform levels of quality, safety and reliability that industrial bodies are more likely to adopt. The process is often initiated and bolstered by stakeholders and private standardization organizations that see the need to apply uniform guidelines and standards. Ultimately, however, the standards and guidelines are adopted by European standardization organizations, including the European Committee for Standardization, the European Committee for Electrotechnical Standardization and the European Telecommunications Standards Institute. By working in close cooperation with industry and other stakeholders, the European Union and European standardization bodies can agree on industrial safety standards and guidelines that are beneficial for individuals, communities, the environment and industrial growth.

In the United States, concern for industrial safety evolved concurrently with industrial development. The Occupational Safety and Health Act of 1970, the first comprehensive industrial safety legislation passed at the federal level, was intended "to assure safe and healthful working conditions for working men and women; by authorizing enforcement of the standards developed under the act; by assisting and encouraging the States in their efforts to assure safe and healthful working conditions; by providing for research, information, education, and training in the field of OHS; and for other purposes."[31] The act emphasized prevention of industrial accidents and illnesses rather than compensation after the fact. It called for the development and enforcement of mandatory safety and health standards. The legislation also established the Occupational Safety and Health Administration and the National Institute of Occupational Safety and Health.[32] An agency of the Department of Labor, the Occupational Safety and Health Administration is responsible for industrial and occupational safety regulation. The enabling legislation incorporates a high level of responsibility for promulgating and enforcing safety norms and regulations.

In the Russian Federation, the main strategic document covering industrial safety is the federal law "On Industrial Safety of Hazardous Production Facilities." Adopted in 1997, the law has been amended several times, yet it stands as an example of consistent regulation for ensuring industrial safety. Regulatory activities are the purview of the Federal Environmental, Industrial, and Nuclear Supervision Service (Rostechnadzor). Rostechnadzor develops state policy and normative legal regulation for industrial safety and conducts control and supervision operations to ensure compliance at hazardous production facilities and transport. It has responsibility for a sprawling hazardous product industry with over 170,000 facilities. As a regulatory and supervisory body, Rostechnadzor takes a risk-based approach to governance, categorizing industrial sites according to their level of risk.

National regulations and standards

Industrial safety regulations consist of a set of national regulations, such as building codes, OHS-related standards, labour and environmental laws, international standards for management, safety management systems and environmental management systems (see Boxes 2.1 and 2.2).[33] To provide optimum protection, laws and regulations addressing industrial safety should follow the best available practices and technologies, and the companies they regulate should adhere to them conscientiously.

Work safety systems have multiple objectives. They aim to establish and improve the responsibility system, guide the formulation of rules and operating regulations, facilitate the formulation and implementation of education and training plans, support the supervision and inspection of rules, eliminate hidden threats in a timely manner, develop and implement emergency rescue plans in the event of an accident and report accidents honestly and expeditiously.

Although construction materials are covered by International Organization for Standardization (ISO) standards, building standards and production sites are subject to national legislation, building codes and industrial safety rules and

BOX 2.1

Industrial safety in China

In China, there are four levels of emergency authority—national, provincial, county and county. At the national level, the Ministry of Emergency Management was established in the context of the institutional reform plan of the State Council. China has a detailed regulatory system for work safety, combining work safety related laws and administrative regulations developed by the state council. The purpose of the Law of Work Safety is to reinforce work safety, prevent and reduce work-related accidents, ensure the safety of people and property and promote sound and sustainable economic and social development (Article 1). The systems established by the work safety law include:

- Responsibilities of principle leading members of units.
- A six-layer management guarantee system.
- An investment guarantee system.
- An employees' rights and obligations system in work safety.
- A security intermediary service.
- A work safety accident emergency rescue and investing system.

Legal liability in work safety includes administrative penalties as well as several methods for enforcing administrative accountability—for example, severe punishment for the principle leading members and for the business entity, with the penalty increasing for not organizing rescue during the incident. There is also criminal responsibility.

Source: Wu Yanyun, China, International Conference on Ensuring Industrial Safety, Vienna, 2019.

BOX 2.2

Industrial safety in Tajikistan

A specially authorized central executive body in Tajikistan regulates industrial safety; supervises the use, protection and geological study of mineral resources; supervises mining; and circulates explosives for civil and industrial purposes. The main functions of the State Control of Safe Work in Industry and Mining Supervision Service are controlling, supervising, and licensing and permitting activities. The service administers the declaration of industrial safety, which includes:

- Requirements for registering explosive material for civil use.
- Standards (norms and rules) on work related to the use of subsoil.
- Requirements for identifying hazardous production facilities.
- Terms for professional training of officials and employees of hazardous production facilities.

Industrial safety laws regulate operation procedures at hazardous production facilities to ensure their safe operation. These laws aim to prevent accidents and ensure that organizations operating hazardous production facilities can properly handle the consequences of accidents. They guarantee restoration of the environment and compensation for losses caused by accidents to individuals, legal entities and the state.

Source: Ardasheri Mirzozoba, Deputy Head, Tajikistan, International Conference on Ensuring Industrial Safety, Vienna, 2019.

standards. Often, however, national government agencies lack the capacity to monitor and enforce these standards and building codes, which puts industrial safety and security at risk. Machines and other equipment are regulated differently by various national authorities. Similarly, international regulations and standards do not cover systems that enhance and confirm industrial safety system, which are in wide use in manufacturing, such as process control systems, emergency shutdown systems, and fire and gas systems.

Industrial safety signs are also subject to national regulations. Used across many industries, they take a multitude of forms and can be complex to navigate. The signs are designed to enhance safety by informing workers, operators and passers-by of potential dangers in particular areas, such as in proximity to equipment or hazardous materials.

In sum, regulations and standards for improving industrial safety are still fragmented. They need to be better understood and properly addressed at the national, and international levels. Guidance on industrial safety regulation and mechanisms of enforcement needs to be formulated, based on good practices and technologies drawn from practices across the globe to enable countries to effectively design and implement their legal provisions in a mutually consistent and complementary manner.

International legal and policy instruments addressing on industrial safety

International safety conventions, standards, norms and best practices on management systems and benchmarking tools increasingly cover multiple aspects of industrial safety, but not all of them (Figure 2.1). The oldest OHS regulations concern accident prevention and minimization of risk during hazardous tasks and exposure to toxic materials and substances. OHS has received prominent treatment internationally, through internationally agreed standards on labour rights, laws and regulations, but gender-based disparities in exposure to risk related to biological differences, employment patterns, social roles and social structures, have not been adequately recognized.

FIGURE 2.1

Key tools and methodologies of international organizations for prevention, preparedness and response to industrial accidents

Organization	Prevention	Preparedness	Response	Post-accident	Learning
Organisation for Economic Co-operation and Development	Guiding Principles for Chemical Accidents, Preventions, Preparedness and Response				Major Accident Reporting System (eMARS)
United Nations Economic Commission for Europe	Transboundary Effects of Industrial Accidents Convention				
European Union	Seveso-III-Directive, Civil Protection Mechanism			Environment Liability Directive	eMARS
United Nations Environment/ Office for the Coordination of Humanitarian Affairs Joint Unit		UN Disaster Assessment and Coordination Mechanism, Flash Environmental Assessment Tool			
United Nations Environment	Flexible Framework, Awareness and Preparedness for Emergencies at Local Level (APELL), Responsible Production Toolkit				
United Nations International Strategy for Disaster Reduction	Sendai Framework for Disaster Risk Reduction 2015–2030				
World Health Organization		International Health Regulations			Event Management System (EMS)
	Public health management of chemical				
European Political Strategy Centre	Member network				Member network

Policy, no intervention · Intervention based · Regulation/legislation/convention

Source: Inter-Agency Coordination Group for Industrial and Chemical Accidents (2019).

International protocols and conventions have tackled some of the negative transboundary spillovers from industrial accidents. For example, the Convention on the Transboundary Effects of Industrial Accidents of the United Nations Economic Commission for Europe (UNECE) has assisted Member States for nearly three decades in improving transboundary cooperation in industrial accident prevention, preparedness and response. This has raised industrial safety standards and practices in signatory countries and yielded valuable lessons that can be shared with other countries through conferences such as UNIDO's International Conference on Ensuring Industrial Safety.

While these international conventions and agreements, some of which are discussed below, have produced tangible results, many countries are still facing multiple industrial safety and security issues due to lack of knowledge, regulations, policies and capacities. Nonetheless, industrial safety regulations are required across many industries, as depicted in Figures 2.2 and 2.3 in the case of the Russian Federation.

FIGURE 2.2

Industrial safety regulations are required across multiple industries in the Russian Federation

Industrial safety	• Mining industry • Metallurgical industry • Coal mining industry • Oil and gas industry • Chemical and petrochemical industry • Explosive facilities of storage and processing of plant raw material • Lifting constructions • Boiler facilities
Safety of nuclear energy use	• Nuclear facilities for peaceful purposes
Safety in power and heat supply, energy efficiency	• Thermal power plants, heat-generating plants and networks • Electrical networks • Consumer power plants and energy efficiency and saving
Safety of hydraulic engineering structures	• Hydropower plants and hydraulic engineering structures
Construction safety	• Extremely hazardous, technically complex and unique capital construction facilities • Activities of self-regulated construction organizations

Source: As presented by Alexander Rybas, Rostechnadzor, International Conference on Ensuring Industrial Safety, Vienna, 2019.

FIGURE 2.3

International commitments to industrial safety by the Russian Federation

Convention on the Transboundary Effects of Industrial Accidents	Signed in Helsinki 17 March 1992
Guarding of Machinery Convention (Convention No. 119)	Signed in Geneva 25 June 1963
Prevention of Major Industrial Accidents Convention(Convention No 174)	Adopted on 80th session of GC ILO in Geneva 22 June 1993
Safety and Health in Mines Convention (Convention No 176)	Adopted on 82th session of GC ILO in Geneva 22 June 1995
Safety and Health in Construction Convention (Convention No 167)	Signed in Geneva 20 June 1988
The Agreement on the Eurasian Economic Union (Annex No. 9)	Signed in Astana 29 May 2014
Agreement on Cooperation in the Field of Industrial Safety at Hazardous Production Facilities	Signed in Moscow 28 September 2001

Source: As presented by Alexander Rybas, Rostechnadzor, International Conference on Ensuring Industrial Safety, Vienna, 2019.

UNECE Convention on the Transboundary Effects of Industrial Accidents and International Atomic Energy Agency conventions. The 1986 fire at the Sandoz agrochemical plant in Schweizerhalle, Switzerland, which released toxic chemicals into the Rhine River, is an example of the severe transboundary effects that an industrial accident can have (Figure 2.4). Soon thereafter, in 1992 the UNECE Convention on the Transboundary Effects of Industrial Accidents was negotiated in order to minimize devastating transboundary effects through prevention and mitigation of their effects. The convention, which entered into force in 2000 and now has 41 signatories, is closely connected to the SDGs, particularly SDGs 3, 6, 9, 11 and 13. The UNECE convention requires parties to identify hazardous activity and to develop contingency plans as well as prevention and preparedness policies. The UNECE convention's vision is expected, by 2030, to "significantly increase industrial safety and reduce the risk of technological disasters by ensuring its full implementation, its wide recognition as a legal instrument for risk reduction under the Sendai Framework and its contribution to achievement of the Sustainable Development Goals."

Nearly 15 years after the Schweizerhalle accident, the breach of a tailings pond dam at a gold mining facility in Baia Mare, Romania, released cyanide

FIGURE 2.4

Transboundary accident at the Sandoz agrochemical storehouse in Schweizerhalle, Switzerland, 1986

Source: Inter-Agency Coordination Group for Industrial and Chemical Accidents (2019).

FIGURE 2.5

The 2000 cyanide spill at the gold mining company Aurul, in Baia Mare, Romania, released cyanide into the Someș River

Source: van Eden (2016).

into the Someș River, contaminated drinking water supplies and devastated fish stocks and other marine life (Figure 2.5).

To avoid more recurrences, the UNECE convention supports countries in preventing accidental water pollution through its Joint Expert Group on Water and Industrial Accidents (joint with the 1992 UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes). An assistance programme in 2004 worked to enhance the capacities of countries of Eastern and South Eastern Europe, the Caucasus and Central Asia in implementing the convention. Multiple guidelines, good practices and checklists have been developed under the convention.

In addition, International Atomic Energy Agency (IAEA) conventions, such as the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, are international legal instruments that support emergency preparedness and response. They constitute the legal basis for the International Emergency Preparedness and Response Framework. The IAEA, along with the signatories to these conventions, has specific obligations to help countries implement the conventions. The IAEA Safety Standards and technical guidance documents and tools outline the requirements, recommendations, guidelines and good practices for building sound emergency preparedness and effective emergency response (see section 3).

Sendai Framework for Disaster Risk Reduction.[34] Apart from nuclear incidents, there are frameworks that deal with other types of disaster risk reduction, such as the Sendai Framework for Disaster Risk Reduction 2015–2030, a voluntary non-binding agreement adopted by Member States in March 2015 at the UN World Conference on Disaster Risk Reduction in Sendai, Japan, and endorsed by the UN General Assembly in June 2015. The United Nations Office for Disaster Risk Reduction has been tasked to support implementation, follow-up and review of the Sendai framework. The goal of the Sendai framework is to "prevent new and reduce existing disaster risk through the implementation of integrated and inclusive measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience."

The framework recognizes the nation state as the primary actor in reducing disaster risk, a responsibility shared with other stakeholders. Acknowledging the increasing impact and complexity of disasters—more than 700,000 people died in disasters in the past decade, more than 1.4 million were injured and 23 million were displaced, and economic losses exceeded $1.3 trillion—the Sendai framework emphasizes the health and well-being of people. Thus, it focuses on managing risks rather than managing disasters. It covers all types of disaster risk and hazards, both natural and human-caused, including biological, technological and environmental hazards. It is intended to serve as a blueprint for multi-hazard disaster risk reduction across all sectors.

Several of the seven global targets of the Sendai framework have direct links to health, focusing on reducing the number of people killed or harmed by disasters, enhancing early warning systems and promoting the safety of critical infrastructure, including health facilities. The framework emphasizes building resilient health systems by integrating disaster risk management into health care provision at all levels and by enhancing the capacity of health workers to understand disaster risk and reduce disaster risk in the health sector.

The Bangkok Principles. To provide a forum for discussing how to assist countries in implementing the health system aspects of the Sendai Framework for Disaster Risk Reduction, the Thai government, the United Nations Office for Disaster Risk Reduction (UNISDR) and the World Health Organization (WHO) convened an international conference of key health and disaster risk reduction stakeholders in March 2016, in Bangkok, Thailand.[35] The conference outcome document, "The Bangkok Principles for the Implementation of the Health Aspects of the Sendai Framework for Disaster Risk Reduction," opened opportunities for collaboration among stakeholders to prevent and reduce the health impacts of disasters. The Bangkok Principles call for an interoperable, multi-sectoral approach to promote cooperation, integration and, ultimately, coherence between disaster and health risk management.

UNISDR continues to provide a platform to enhance cooperation between disaster risk reduction leaders and health communities to strengthen national capacity for disaster risk management. It is developing practical guides on human-caused hazards, including technological hazards, and is raising awareness of biological and technological hazards among policy-makers and the public.

The Seveso Directive and related actions in the European Union.[36] In Europe, the catastrophic industrial accident in 1976 in a small chemical plant in the Italian town of Seveso in 1976, approximately 20 kilometres north of Milan, prompted the adoption of the Seveso Directive to address accident hazards. The Seveso Directive, a benchmark for industrial accident policy and a model for legislation in many countries worldwide, has contributed to the low frequency of major industrial accidents in the European Union, despite the high rate of industrialization. The directive has four main pillars—prevention, preparation, response and lessons learned—intended to generate a continuous cycle of improvement. Other EU measures complement these efforts, including the EU Civil Protection Mechanism, the Environmental Liability Directive, the CBRN-E (chemical, biological, radiological, nuclear and explosives) action plan and the Mining Waste Directive.[37]

2.2. Standards and norms for ensuring industrial safety

Standards are a powerful way to ensure safety and minimize risk. Standards enable industries and organizations to demonstrate that they are following good practice, allowing them to have meaningful conversations with their clients and customers about the quality of their products and services.[38]

Standards allow for economies of scale and, particularly in a global economy, establish a single standard globally. Standards thus enable compatibility and consistency, which drive resource efficiencies and help industries and organizations work more effectively and build resilience into their global operations. When all actors within an industry work towards the same standard, transaction costs fall, including those related to losses from industrial accidents, resulting in further economies of scale through the supply chain and lower social and environmental costs.

Innovation means that standards cannot remain static. They are related to best practice and therefore reflect innovation within an industry, while also fostering innovation by exploring not only what can be done but also what can be done better.

Standards are an effective tool when handled properly. However, the fulfilment of certain international standards or norms does not necessarily create totally safe conditions or provide fully effective protection of workers. For example, standards related solely to equipment might have only a muted impact on safety. Certification schemes can help, by ensuring that a certain level of safety is achieved, but doing so effectively requires the backing of supervisory authorities and legislation. Some of the opportunities and challenges of industrial safety standards are listed in Table 2.1.

There are a great number of international, country-specific and industry-specific standards that can help industries and organizations improve industrial safety and elevate OHS standards, but the sheer volume of standards can also be a challenge. For example, there are 111 standards on occupational safety and industrial hygiene, 286 standards on ergonomics and 285 standards on equipment safety. Including ancillary standards, such as fire protection and personal protective equipment, boosts the total number of standards to more than 5,000—and that is without considering standards that benefit OHS, including asset management, business continuity and facilities management.[39]

International labour standards on occupational health and safety

The constitution of the International Labour Organization (ILO) specifies that workers must be protected from sickness, disease and injury arising from their employment. Yet millions of workers around the world remain unprotected. Losses arising from breaches in OHS, including lost compensation and work days, interrupted production, training and reconversion costs, and health care expenditure, total some 3.9 percent of annual global GDP. And companies face additional costs in the form of early staff retirements, loss of skilled staff, absenteeism and high insurance premiums. Many of these costs are preventable through the implementation of sound practices in accident prevention, reporting and inspection.

ILO standards on OHS provide essential tools to help governments, employers and workers establish safe practices. The ILO has adopted more than 40 standards dealing with OHS (Figure 2.6) and a similar number of codes of practice. Nearly half of ILO instruments relate directly or indirectly to OHS issues.[40]

TABLE 2.1
Opportunities and challenges of industrial safety standards

Opportunities	Challenges
Strengthening international acceptance and credibility	Accessibility
Making workplaces safer and healthier (decent work)	Duplication
Enabling continual improvement	Complexity
Sharing good practice and learning	Resources to implement
Addressing emerging concerns	Inconsistent views of standards
Improving compliance with regulations	Sector-specific initiatives
Enabling interoperability along supply chains	

Source: International Conference on Ensuring Industrial Safety, Vienna (2019).

Nuclear safety standards

Industries apply nuclear technologies extensively to improve product quality and safety, benefiting both producers and consumers.[41] Making nuclear and radiation technologies safe and secure is a priority. Safety and security underpin the work of the IAEA, whose founding statue calls on it “to

FIGURE 2.6

Classification of International Labour Organization international labour standards on occupational health and safety

THE ILO HAS ADOPTED MORE THAN 40 INTERNATIONAL LABOUR STANDARDS SPECIFICALLY DEALING WITH OCCUPATIONAL SAFETY AND HEALTH. THESE STANDARDS CAN BE CLASSIFIED AS THOSE:

a) RELATED TO SPECIFIC RISKS

(such as ionizing radiation, asbestos, occupational cancer and chemicals)

b) RELATED TO SPECIFIC SECTORS OR BRANCHES OF WORK ACTIVITY

(such as agriculture, construction and mining)

c) ENCOMPASSING GENERAL PRINCIPLES AND OUTCOMES

(such as those relating to management of OSH, labour inspection and welfare facilities)

d) DEALING WITH THE FUNDAMENTAL PRINCIPLES OF OCCUPATIONAL SAFETY AND HEALTH:

- **Occupational Safety and Health Convention, 1981 (No. 155) and its Protocol of 2002;**
- **Occupational Health Services Convention, 1985 (No. 161); and**
- **Promotional Framework for Occupational Safety and Health Convention, 2006 (No. 187).**

Source: ILO (2019).

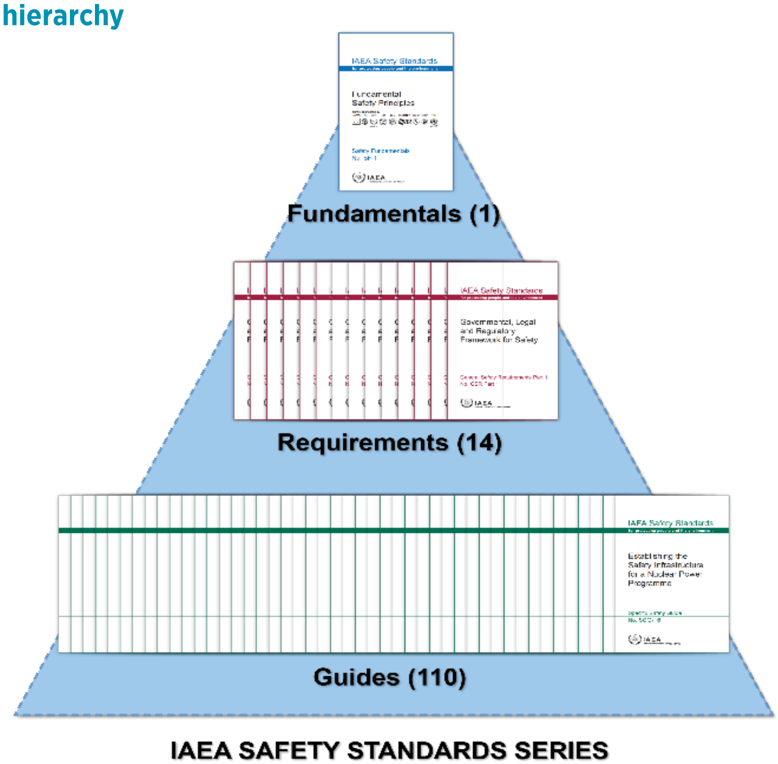
accelerate and enlarge the contribution of nuclear technologies to peace, health and prosperity throughout the world." The statute tasks the IAEA with creating standards of safety to protect health and minimize the danger to life and property and to provide for the application of these standards to help its Member States remain safe and secure in the use of nuclear and radiation technologies.

The IAEA's Safety Standards incorporate more than a hundred documents that reflect a consensus on what is considered a high level of nuclear and radiation safety—the basics of how to establish, maintain and continuously improve political, legal, and regulatory frameworks for nuclear and radiation safety. The standards are not binding, but Member States are encouraged to apply them, and many Member States adopt or adapt them in their legislative and regulatory systems.

The Safety Standards consist of three sets of publications (Figure 2.7): the Safety Fundamentals, which establish the safety objective and principles

FIGURE 2.7

International Atomic Energy Agency safety standards hierarchy



Source: IAEA (n.d.).

of protection and safety; the Safety Requirements, which set out the obligations to ensure the protection of people and the environment, now and in the future; and the Safety Guides, which provide recommendations and guidance on how to comply with the requirements.[42]

ISO standards on industrial safety

The International Organization for Standardization (ISO) developed ISO 45001 on OHS to help organizations improve employee safety, reduce workplace risks and create better, safer working conditions all over the world. The standard was developed by a committee of OHS experts and follows other management system approaches such as ISO 14001 on environmental management systems and ISO 9001 on quality management systems. ISO 45001 was based on earlier international standards in this area, such as the UK Occupational Health and Safety Assessment Series (OHSAS) 18001 on OHS management systems, the ILO-OHS Guidelines, various national standards and the ILO's international labour standards and conventions.

ISO 45001 increases organizational resilience through proactive risk prevention, innovation and continual improvement; strengthens legal and regulatory compliance while reducing business losses; demonstrates brand responsibility by committing to safe, healthy and sustainable work; and establishes a single global OHS system for all businesses, of all sizes. ISO 45001 also supports Sustainable Development Goals (SDGs) 3, 5, 8, 9, 10, 11 and 16 (Figure 2.8); organizations committed to sustainability are increasingly aligning their corporate strategies to the SDGs. Accredited certification of ISO 45001 demonstrates an organization's commitment to ensuring decent work conditions and employee health, well-being and equality practices. For organizations seeking to enhance their environmental, social and governance profile, implementation of ISO 45001 and its alignment to the SDGs send a powerful message to shareholders and stakeholders, including employees, that the organization cares for its workers.[43]

FIGURE 2.8
ISO 45001 contributes to at least seven Sustainable Development Goals

The Sustainable Development Goals that ISO 45001 contributes to

Source: BSI (n.d.).

ISO Technical Committee 283

ISO Technical Committee 283, established in 2018 after the publication of ISO 45001 for OHS management, has 71 participating members and 19 observing members.[44] It seeks to:

- Develop and publish formal and informal documents to support effective implementation of ISO 45001 in all types of organizations.
- Identify trends and challenges in different sectors, types of organizations and regions; identify data sources and develop material to drive improvement of OHS performance.
- Develop the online and social media presence of the technical committee as a means of gathering feedback and data to identify and prioritize the committee's work programme, raise awareness of the committee's work and encourage debate.
- Develop a package of materials and online content to promote and support application of the principles of ISO 45001 by small and medium-sized enterprises (SMEs) and establish channels, including partnerships with SME associations, for engaging with SMEs that are unaware of standards or that fail to see the value they can deliver.
- Explore and possibly establish metrics to track progress on SME engagement, and review progress at least annually in the period to 2021.

2.3. Industrial safety management systems and best practices

OHS is vital for any organization. An accident or illness at the workplace can affect not only employees, but also business operations and the sustainability performance of firms through lost working hours and production delays and by diminishing the quality of an enterprise's product and its reputation. To avoid such problems, many organizations have adopted OHS and sustainability management systems. Many organizations use sustainability and OHS reviews (or audits) to assess their performance. However, these reviews and audits may not be sufficient to ensure that performance meets the legal and policy requirements of the organization. To do that, the reviews must be carried out within a structured management system that is embedded in the organization.

While internal OHS management system standards cannot replace national laws, regulations or accepted standards, they can support and promote efficient OHS practices while also meeting socio-economic goals.[45] In an interconnected system of industrial safety standards, each component has limitations, but integrating them improves industrial safety. Thus, voluntary standards, alongside regulation, can help organizations provide a safe and healthy work place because they incorporate good practices that have been developed through consensus.

Industrial safety management systems

An industrial safety management system consists of interrelated organizational and technical measures whose objective is to prevent accidents and injuries and to contain or eliminate their consequences. As such, an industrial safety management system is a framework for managing health and safety risks across all business activities rather than dealing with one risk at a time—where "risk" is the likelihood that someone (or something) will be harmed by a hazard (any insecure condition with strong potential for creating harm or damage)[46] Industrial safety management systems are not required by law. It is up to each company to decide whether going beyond basic legal requirements is appropriate for its business and if it will benefit from implementing a structured management system.[47]

OHS, including compliance with OHS requirements under national laws and regulations, comes under the purview of industrial safety management systems, of which it is a key constituent. Organizations should show strong leadership and commitment to OHS activities and establish an appropriate OHS management system. The main elements of such a system are policy, organizing, planning and implementation, evaluation and action for improvement (Figure 2.9).

Setting up an OHS management system within an organization creates a frame for the sustainable development, implementation and review of OHS plans and processes, which are essential for OHS management in the workplace.[48] OHS is a management function and requires extensive management

FIGURE 2.9
Main elements of an occupational health and safety management system

Source: ILO (2001).

BOX 2.3
Qualitative management of an industrial safety system

Qualitative management of the industrial safety system at a hazardous production facility calls for the following to be carried out regularly:

- Identifying and updating information related to applicable laws, regulations, permits, licenses and other legally binding requirements and agreements, codes, standards and regulations.
- Documenting and communicating this information to employees.
- Ensuring compliance with laws, regulations, permits, licenses and other legally-binding requirements and agreements, codes, standards and rules for conducting work.

One of the recognized mechanisms in applying an industrial safety management system at a hazardous production facility is showing that senior and middle-ranking managers are actively ensuring compliance with laws and regulations. All cases of non-compliance should be monitored to understand how the situation developed and how the problems could be eliminated. This includes:

- The participation of supervision authorities and administrative control bodies.
- The introduction of changes to instructions for compliance with normative-legal requirements.
- The inclusion of valuable information and gained experience to improve and prevent the recurrence of similar incidents.

Source: Marhavilas et al. (2018).

engagement. Performance goals must illustrate management objectives. An OHS management system acknowledges that occupational accidents, injuries and diseases are an indication of a problem in the system rather than a result of human error.

OHS management systems have evolved considerably since they were introduced in the 1970s. Changes have been driven by several factors, including the structure and functioning of the organization. OHS systems must link people, the environment and technical systems in a way that reflects an organization's unique features.

A joint study of the British Safety Council and the ILO demonstrated that organizations that have adopted an OHS management system had higher productivity, fewer workers absences, fewer compensation claims and insurance costs, higher worker morale and work focus, and a more positive company image among customers and suppliers.[49]

Despite the indisputable benefits of having an integrated OHS management system, not all enterprises can afford to allocate adequate financial and other organizational resources to develop and implement such systems. To work efficiently, an integrated industrial safety system requires a heavy investment in organizational time to develop a culture of safety in a company (Box 2.3). Seeking industrial safety certification is one way to improve industrial safety systems, reduce occupational risks, control the impact of hazardous production factors, prevent incidents or accidents and reduce current or unplanned post-accident costs.

Best practices

Global best practice is to have an OHS management system at a hazardous production facility to ensure compliance with requirements and agreements affecting the reliability of operations and to enable assessment of the environmental, socio-economic and health effects on workers. Such a system also provides for continuous compliance with standards, general principles and rules for conducting work that contributes to the reliability of operations.

There is always room for improvement in the governance of industrial safety. Good governance is the application of the best known techniques for reducing or mitigating safety risk. Governance should be flexible in a way that drives stakeholders to consider not only current but also potential risks, to avoid complacency.[50]

For OHS, which is often regulated along national lines, there is considerable value in expanding the number of organizations operating in more than one country to develop international, consensus-based best practice. Today, many companies are involved in global supply chains, so the establishment of a common vocabulary around OHS management is a necessity.[51]

3

CREATING A CULTURE OF INDUSTRIAL SAFETY AND SECURITY

An organization's safety culture affects the ways in which individual entities within an organization think and behave with respect to safety.[52] Ensuring safety has come to be understood as an organizational effort, rather than an individual responsibility, and an indispensable part of an organization's operations and growth strategy. Safety culture can be defined as "an evolving set of practices (ways of doing) and a mindset (ways of thinking) that is forged gradually in an organization and is widely shared by its members when it comes to controlling the most significant risks associated with its activities."[53]

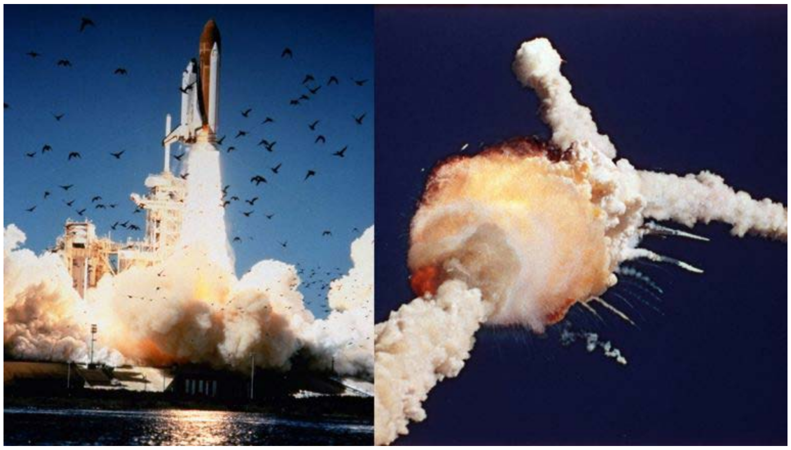
3.1. The emergence of the concept of an organizational safety culture

> "Safety culture is about people, changing perspectives, mindsets, and experiences."

The term *safety culture* came into common use in the 1980s after two major accidents: the explosion of the US space shuttle Challenger on 28 January 1986, killing all seven astronauts aboard (Figure 3.1), and the Chernobyl nuclear accident on 26 April 1986 (Figure 3.2). *The Challenger Launch Decision: Risky Technology, Culture and Deviance at NASA,* by Diane Vaughn, notes the role of the organizational culture at the National Aeronautics and Space Administration (NASA) that led to the Challenger disaster: "The decision to launch Challenger was, incredibly and sadly, a mistake embedded in the banality of organizational life. No fundamental decision was made at NASA to do evil; rather, a series of seemingly harmless decisions were made that incrementally moved the space agency toward a catastrophic outcome."[54] Vaughn concludes that the launch decision resulted not from managerial wrongdoing, but from deep-rooted structural factors that influenced decision-making and resulted in the tragic mistake.[55]

The immediate cause of the Challenger accident was reported as a technical failure of the O-rings sealing a critical joint in the rocket booster.[56] However, further investigation revealed that economic factors had dominated safety procedures and that NASA had overlooked warnings from suppliers about the problems that low overnight temperatures could cause for the O-ring joint.[57]

FIGURE 3.1
Lift-off and explosion of the space shuttle Challenger, 28 January 1986



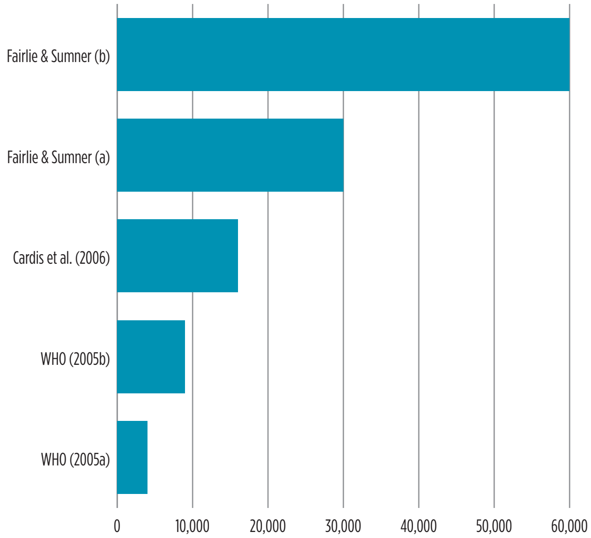
The Space Shuttle Challenger lifts off (left) and explodes shortly after (right) over the Kennedy Space Center, Fla., All seven crew members died in the explosion, which was blamed on faulty O-rings in the shuttle's booster rocket.

Source: https://whyy.org/. Bruce Weaver/AP Photo.

FIGURE 3.2
The Chernobyl nuclear-power plant a few weeks after the disaster of 26 April 1986

Source: The Atlantic (2019).

FIGURE 3.3
Estimated number of deaths from the Chernobyl nuclear accident



Note: WHO (2005a) refers to the number of deaths (up to 4,000) estimated in the populations with highest exposure to radioactive fallout from the incident. WHO (2005b) add this to further estimates by the WHO [not included in its report] on the potential death toll in individuals beyond proximate areas. Fairlie and Sumner (2006a) and (2006b) represent their published lower and upper estimates, respectively.
Source: WHO (2005); Fairlie and Sumner (2006); Cardis et al. (2006) available in Our World in Data (IAEA 1992).

Recent studies indicate that several deep-rooted flaws in the safety culture at NASA (introduced during several years of reorganization) help explain the decisions made by front-line managers in the final hours before the launch and contributed to the disaster. These included competition between research and development teams, poor information flow and distrust of whistle-blowers.[58]

The Chernobyl nuclear accident in April 1986 was the second major disaster in 1986 that drew attention to organizational safety culture, as a series of explosions destroyed Chernobyl's reactor number 4. The World Health Organization (WHO), in its 2005/06 assessment "Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts," estimated that the Chernobyl nuclear accident will ultimately results in about 4,000 deaths among the proximate populations of Ukraine, Russian Federation, and Belarus that were exposed to high radiation levels. If people across the region who were exposed to low-level radiation are also included, the eventual death toll rises to 9,000.[59] Other estimates are even higher (Figure 3.3).

After the incident, the International Atomic Energy Agency (IAEA), in its International Nuclear Safety Advisory Group (INSAG) reports in 1986 (INSAG-1) and 1992 (INSAG-7), found that a major contribution to the disaster was a deficient safety culture at all levels—design, engineering, construction, manufacture and regulatory and operational.[60]

Analyses of these and many other industrial accidents indicate that they cannot be explained exclusively by the attitudes or actions of front-line staff.[61] Rather, the major contributors to the accidents were systemic flaws that were built into the safety culture at all levels of management in the responsible organizations.[62] This reality is reflected in multiple definitions of an organization's safety culture (see Box 3.1).

Organizations are responsible for adopting and cultivating a safety culture that can be fully integrated into their systems through the involvement

BOX 3.1
Definitions of organizational safety culture

The International Nuclear Safety Advisory Group of the International Atomic Energy Agency defines safety culture (INSAG-4, 1991) as the "assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance" (International Nuclear Safety Advisory Group, 1988).

Others have defined safety culture in similar ways:

"The safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organization's health and safety management. Organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of the importance of safety and by confidence in the efficacy of preventive measures." Advisory Committee on the Safety of Nuclear Installations (HSC, 1993; HSE 2005).

"Those aspects of the organizational culture which will impact on attitudes and behaviour related to increasing or decreasing risk" (Guldenmund 2000).

"The attitudes, beliefs and perceptions shared by natural groups as defining norms and values, which determine how they act and react in relation to risks and risk control systems" (Hale 2000).

"Safety culture is a sub-element of the overall organizational culture. It is an abstract concept which is underpinned by the amalgamation of individual and group perceptions, thought processes, feelings and behaviour which in turn gives rise to the particular way of doing things in the organization. Safety culture factors in turn will characterize and influence the deployment and effectiveness of the safety management resources, policies, practices and procedures." Eurocontrol (Gordon et al. 2006).

"A positive Safety Culture is a culture in which safety plays a very important role and is a core value for those who work for the organization. This contrasts with organizations in which safety concerns are treated as marginal or an irritating diversion from the real business." The International Association of Oil and Gas Producers (IOGP 2013).

"Safety culture is defined as the core values and behaviours resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals, to ensure protection of people and the environment" (WANO 2013).

of employees. A proactive stance towards safety and an unconditional focus on people and the environment should be the key factors to consider while engaging in deliberations on safety culture.

> "Following the rules are the difference makers for someone going home to their family at the end of the work day."

3.2. Approaches to establishing a safety culture

Given that a safety culture is a characteristic of a group or organization and that safety is only one among a diverse set of priorities of an organization, there are several ways to approach creating a safety culture. However, there are two key paths to establishing a safety culture within an organization: rule-based safety and managed safety.[63]

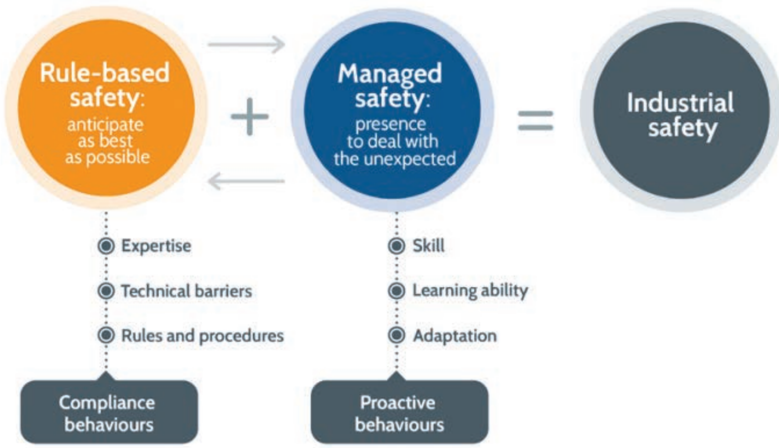
Rule-based safety implies compliance with an organization's safety rules and regulations, which generally reflect the anticipation of hazardous situations by safety experts and occupational safety professionals. *Managed safety* demands the active participation of staff and reliance on the professional expertise of staff present during a real-time emergency or hazard. It depends on the ability of front-line workers to respond effectively and efficiently to a hazardous situation. Rule-based safety and managed safety can be applied in the same organization, as a preventive measure and a mitigation measure (Figure 3.4). A rule-based safety culture can prevent industrial accidents through compliance with regulations and industrial safety standards. Moreover, abiding by rules on how to act during an emergency is also an excellent mitigation strategy. A managed safety culture ensures hazard prevention as well as mitigation through the appropriate actions of staff in the event of an industrial accident.

Striking the right balance between rule-based safety and managed safety is crucial for promoting an effective safety culture within an organization.

> "Safety culture in an organization will thrive best when people in the organization take accountability for their own safety as well as of their fellow workers"

FIGURE 3.4

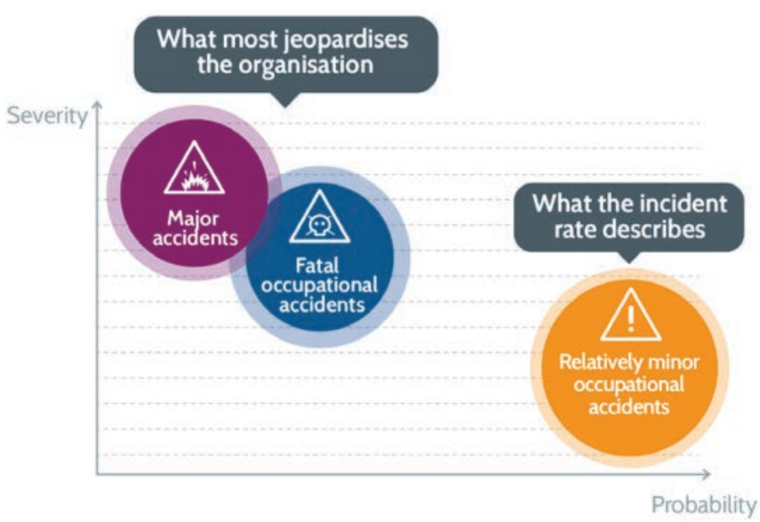
How rule-based safety and managed safety contribute to industrial safety



Source: ICSI (2017).

FIGURE 3.5

Differing degrees of severity and probability of major and minor industrial accidents



Source: ICSI (2017).

Both approaches to industrial safety should take into account the differences in severity and probability of major and minor accidents that may occur in an organization. Major (and fatal) accidents can jeopardize an organization's existence and thus have severe consequences, but their probability is generally lower (Figure 3.5). Minor OHS issues have a less severe impact on an organization (for example, psychological distress, tension due to work-related stress), but they are more common.

The attention given to workers on issues of OHS is two-sided. On the one hand, workers shape the safety culture every day. Their perceptions about safety become the reality of safety in the field. On the other hand, workers are often the primary beneficiaries or objects of an OHS culture, depending on the nature of the culture in a particular organization. This means that workers need to feel safe about raising issues of safety, which in turn means that management needs to create a retaliation-free space for employees to express their concerns.

Both health and safety should be at the heart of employee education program. The health aspect in OHS is often neglected. That is because the health consequences of dangerous or hazardous situations are much more difficult to recognize than major safety-related disasters and emergencies and often occur after a long delay. For example,

BOX 3.2
Behaviour-based safety at ExxonMobil

ExxonMobil's understanding of the need to improve health and safety as well as the company's dedication to a simple and clear vision of "nobody gets hurt," are the starting points for its commitment to a behaviour-based approach to safety. In 1999, long before Exxon's merger with Mobil, Exxon improved safety by implementing engineering standards and by applying traditional safety programs. After the merger, this was continued. In 1999, by implementing a comprehensive 11-element operations integrity management system, ExxonMobil strengthened its health and safety performance.

Between 1990 and 1997, the company reduced its global rate of incidents by around 60 percent. But when the company's initial performance stagnated, ExxonMobil realized that to accomplish its vision, further innovation would be required. To do this, four factors were considered critical. First, managers are active, involved and committed as leaders. Second, supervisors are capable of applying safety management tools and systems. Third, the workforce believes all possible accidents and injuries are preventable. Furthermore, the workforce is capable of consistently recognizing and mitigating hazards. Fourth, individuals are accountable for their own safety and are prepared to intervene to safeguard others. The first two factors target the role of leadership, which should demonstrate commitment as well as personal accountability to safety, and encourage an environment of openness and trust, which is needed for effective behaviour-based safety activities. Leaders should recognize the impact of their own behaviour and they should acquire the necessary skills to successfully involvement employees.

The third and fourth factors relate to the workforce, as the adoption of behaviour-based safety is based on the belief that ExxonMobil's workforce has a crucial role to play. All employees need to be engaged and involved in the identification and avoidance of unsafe conditions and behaviour. To achieve this, they should be prepared to accept leadership in safety from anyone.

The "job observation and intervention process," part of behaviour-based safety at ExxonMobil, has one simple objective and three implementation strategies. The objective is that the workforce proactively and routinely identifies and eliminates unsafe behaviour by anyone. The strategies are:

- First, a process for active employee involvement is in place.
- Second, a systematic site-wide observation and intervention process is implemented.
- Third, individuals from different sites, who can assist and advise the management team, are identified.

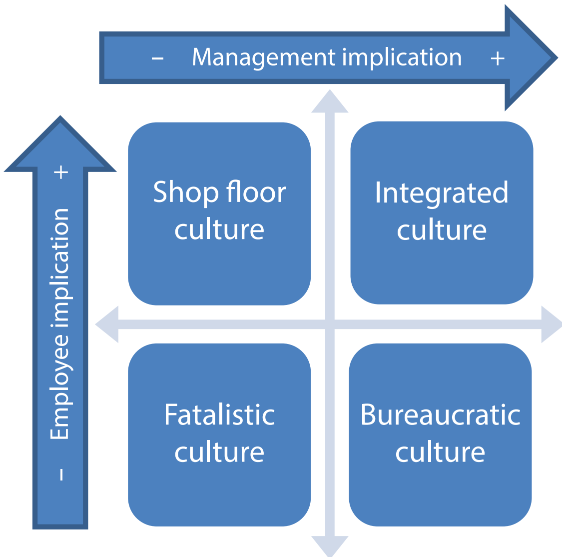
In the mid to late 1990s, some of ExxonMobil operating sites implemented behaviour-based safety. In 2000, the job observation and intervention process was implemented globally at all ExxonMobil organizations. This resulted in a global incident rate decrease of about 50 percent between 1997 and 2002. What is more, in 2003 the U.S. Occupational Safety and Health Administration lost-time incident rate for around 200,000 employees and contractors was 0.065 per 200,000 hours for employees and 0.099 for contractors. Against this background, ExxonMobil continues its commitment to behaviour-based safety and its vision of reducing accidents and incidents to a rate of zero.

Source: Whiting and Bennett (2003).

the harmful effects of exposure to dangerous substances are often apparent only after years or even decades. The health implications of OHS should not be overlooked because of their invisibility in the short term.[64]

The roles of employees and management differ in the four main types of safety culture: *fatalistic* (influencing the level of safety is considered impossible, so management and employee involvement in implementing a safety culture is the lowest), *shop floor* (informal safety practices are developed by workers to protect themselves), *bureaucratic* (the formal safety system predominant in high-risk industries, with a top-down approach where the company and managers are responsible for implementing safety requirements), and *integrated* (safety leadership that is both top-down and bottom-up, wherein all are held responsible for the firm's safety level) (Figure 3.6).[65]

FIGURE 3.6
Types of safety culture



Source: Daniellou, Simard and Boissières (2011).

FIGURE 3.7
Eight safety factor for describing an organization's safety culture

Source: American Bureau of Shipping (2012).

The American Bureau of Shipping, in its guidance notes on safety culture and leading safety indicators, has outlined eight safety factors that describe a safety culture: communications, empowerment, feedback, mutual trust, problem identification, promotion of safety, responsiveness and safety awareness (Figure 3.7).[66] All of these factors should cascade through all levels of the organization to establish and maintain a safety culture.

Communication is a vital part of establishing an OHS culture. Robust communication channels should exist vertically and horizontally within an organization, reflecting the importance that everyone in an organization understand the information required for safe operations. Individuals in a team or organization should feel *empowered* to fulfil their safety responsibilities through delegations of authority and resources. Team leaders should encourage the sharing of safety concerns and provide clear assignment of responsibility and accountability for safety responsibilities. Management and team leaders should provide timely *feedback* on OHS concerns, with priority given to the timely communication of and response to incidents and investigations. Mismatches between practices and procedures or standards should be resolved as soon as they are noticed.

> "Leadership plays a significant role in setting the culture since they make the decisions that condition how risk is managed."

Relationships within an organization should be characterized by *mutual trust*. Members in an organization should be able to trust their leaders to do the right things in support of OHS and should shoulder their share of responsibility for performance by reporting potential problems and concerns. Having confidence that a just system exists, in which honest errors can be reported without fear of reprisal, is integral to sustaining an organization's safety culture. *Problem identification* means that each member should have adequate training to recognize unsafe acts and conditions and to be aware of the steps needed to avoid or mitigate them.

Promotion of safety through visible, active and consistent support for safety programs must be a core strategy not only in the factory or industrial site, but also within management of the organization. All members of the workforce should be equipped through emergency preparedness training and full personal protection equipment to be *responsive* to the demands of the job, including unexpected events and emergencies. A strong sense of *safety awareness* should pervade the organization. All members of the workforce need to be aware of their responsibility for their own safety and the safety of co-workers, the organization and the environment. All employees should feel accountable for their own actions and, collectively, for the actions of their colleagues. A strong individual and group intolerance of violations of established safety performance norms is essential.

3.3. Methods of building and changing a safety culture

Building a safety culture involves all parts of an organization, and all the factors that generate risk for employees and the environment should be taken into account. While each organization and its risk factors differ, some common methods can be applied in building a resilient safety culture.[67]

Demonstrating management commitment. Management commitment is fundamental for building a strong safety culture. Having a formal process for safety-related corrective action is one of the best ways to demonstrate management's commitment to a resilient safety culture. Another is to incorporate OHS in strategic planning, making the organization proactive rather than reactive to safety concerns. Other methods for management to demonstrate commitment to safety culture are to establish a joint worker–management committee on OHS, convene regular jobsite meetings on OHS, set clear OHS expectations, incorporate prevention into design and use OHS data to improve practices.

Aligning OHS with other organizational values. Organizations should value OHS at least as much as they value productivity, reward attention to OHS and encourage OHS mentoring. While safety is not the only priority of firms, keeping it on par with other priorities such as productivity and profits is necessary for building a positive safety culture. Rewarding workers who report safety-related incidents and mentoring staff in identifying safety-related incidents would help integrate safety as an organizational value.

Ensuring accountability at all levels. Holding everyone accountable for safety, taking near-misses seriously and investigating them promptly and thoroughly, conducting regular and surprise inspections of industrial facilities and office spaces, and using external OHS audits can help ensure accountability at all levels.

Improving supervisory leadership. Considering strong safety leadership as an important attribute of supervisors and rewarding supervisors who lead by example and who monitor and mentor employees and contractors on safety practices can improve supervisory leadership on safety.

Empowering and involving workers. An open-door policy for workers to report hazards, incidents and concerns empowers them to report unsafe conditions and near-misses. Asking workers for input on OHS conditions, giving them stop-work authority, involving them in OHS planning and including them in job-hazard analyses can give them opportunities to be aware of safety issues, raise concerns and act promptly during emergencies. Also helpful are regular safety meetings with jobsite workers and supervisors.

Improving communication. Clearly and consistently communicating corporate OHS policies, ensuring that managers regularly engage with workers one on one and coordinating OHS policies with all stakeholders can fill safety communication gaps in an organization.

Training at all levels. Training on OHS is essential at all levels, from the shop floor to management. Improving safety requires changes to ongoing workflows and shop floor arrangements. Organizations are finding that making safety training personal and keeping employees engaged in safety monitoring beyond the training classes are helping them bring their safety message more effectively to workers.

Encouraging client involvement. Providing opportunities for clients to participate in OHS activities by engaging them in the monitoring of onsite OHS performance can give organizations an outsider perspective, which may bring to light many discrepancies that are not visible from within.

Several general principles should be kept in mind while building an organization's safety culture in these ways.[68]

Moving from diagnosis to action. The diagnosis and evaluation of an organization's safety culture is the starting point for launching change. A common mistake is to attempt to implement a vast number of uncoordinated corrective actions that aim to fix any and all problems within the organization quickly, but cannot do so sustainably. Real change happens only over the medium to long term and must extend beyond practices and actions to mindsets. This implies a shared conviction that change is necessary; adequate resources, including time; mobilization of all actors; steadfast commitment from top managers, who are willing to reassess their own practices; and a readiness to seek input from outside observers who can provide constructive criticism.

Understanding that changing the safety culture takes time. It is impossible to change the safety culture of an organization without changing the organizational culture that nourishes it. And that takes time. Improving safety performance is an iterative process that requires unwavering commitment from all concerned.

Identifying the goal and setting the course. A well-integrated safety culture relies on a high degree of involvement from both management and employees. Starting from a shared understanding of the current situation, the first step is to co-construct a vision of the future safety culture: the goal. Where does the organization want to go and why? Who are the key people who can support this change? What are the strategies for change, and in what time frame?

Changing an organization's safety culture can be difficult (Box 3.3). A five-step approach to changing the safety culture includes diagnosis, vision, programme, resistance management and the anchoring of safety culture values (Figure 3.8). The approach supports the implementation of values and sustainable practices that can help manage the major risks linked to the organization's activities.[69]

3.4. Firm-level safety culture

Nurturing a safety culture allows an organization to improve its safety performance by training employees to adopt certain safety values. As mentioned, creating an industrial safety and security culture is a long-term process that requires setting goals and identifying key performance indicators to measure progress. Adherence to regulatory requirements is an integral part of an organization's safety culture, but that is just a beginning. Raising the awareness of risk within the entire industrial sector can also contribute to the creation of a safety culture within an individual organization.

The culture of an organization affects what the organization considers worth paying attention to and what it thinks can be ignored. In safety-critical industries, a major incident may be the first time that an organization focuses seriously on aspects of safety that it had overlooked. A program for developing a safety culture must, therefore, be based on a solid understanding of the overall culture of the organization. This makes external safety culture assessments an important mechanism for enabling organizations to understand the

BOX 3.3
Changing safety culture

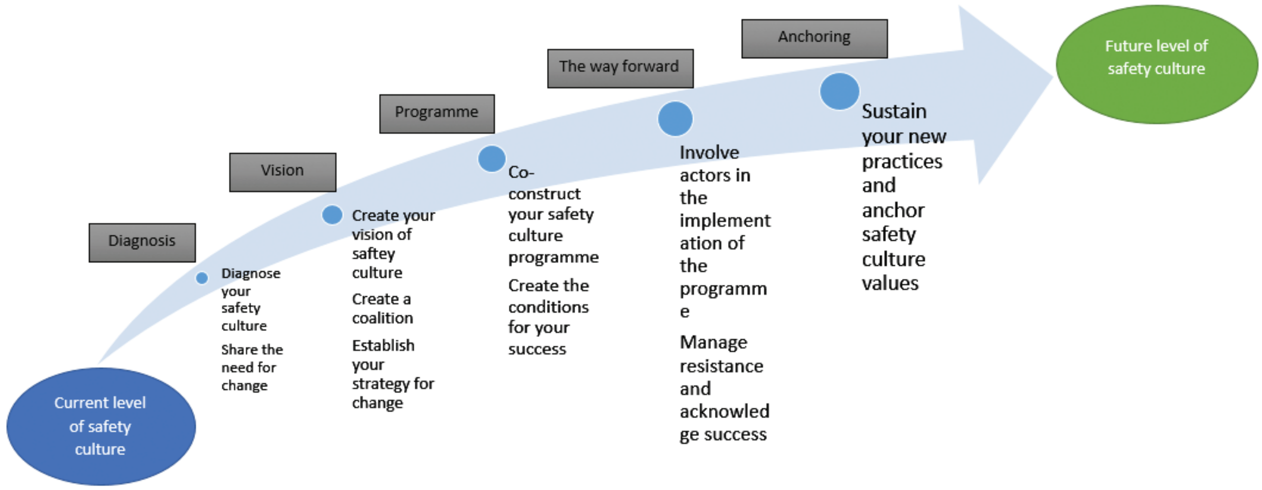
The German Motor Vehicle Inspection Association DEKRA (Deutscher Kraftfahrzeug-Überwachungs-Verein) offers a range of services related to safety and industrial operations, such as training, certification, building surveys, accident analyses, technical reports, corporate consultancy, environmental assessments and material and product testing. Their success with BNSF Railway suggested a six-step process to changing to a safety culture:

1. *Accept that the status quo is unacceptable.* Despite initial safety programmes, BNSF Railway was still experiencing fatal accidents. The trigger was when the company resolve that "Any loss of life is unacceptable." Leadership, and the safety culture in which safety processes are executed, also need to change.
2. *Be patient (true change takes time).* It takes patience to change safety culture because it deals with people who have been in the industry for 30 years and they have seen safety programs come and go. It is about changing people's perspectives, mindsets and experiences, and this takes a long time.
3. *Start with rule compliance.* The first key to changing a safety culture is rule compliance. Rules need to be consistent and employees need to be able to assess exceptions and disciplinary outcomes. People need to be held accountable and procedural justice needs to treat all employees equally.
4. *Make sure leaders stay on message.* It is critical that the company makes sure its leaders are consistent with messaging and focus. Leaders set the culture, and culture determines behaviours. Safe behaviours get people home at the end of the day. Consistent messaging will start to build a level of trust in the organization.
5. *Involve your informal safety leaders.* To lend impetus to changes, invite the company's informal safety leaders into the cultural change initiative. Informal safety leaders then become brand ambassadors for change.
6. *Encourage people to take care of their co-workers.* The final step is to turn safety compliance into a safety commitment. This is best described as people taking accountability for their own safety while looking out for their co-workers when they see their co-workers putting themselves at risk. BNSF Railway shifted commitment from push to a pull where employees and labour unions became the driving force for safety improvements.

There is no simple one-size-fits-all method to changing a company's culture. The success at BNSF Railway was built on in-depth assessments, analyses, and strategic planning carried out jointly by BNSF and DEKRA to have safety take root as a value at BNSF. Safety culture can only change if a company's values change, and values are often deeply rooted.

Source: DEKRA North America (2018).

FIGURE 3.8
A five-step approach to changing an organization's safety culture



Source: ICSI (2017).

BOX 3.4

The DuPont™ Bradley Curve™

In 2009, a DuPont Sustainable Solutions' (DSS) study using the Bradley Curve™ showed a direct correlation between an organization's cultural strength and an organization's safety culture, including injury frequency rate and sustainable safety performance. Using data collected since 1999 by the DuPont™ Safety Perception Survey™,[1] the DuPont™ Bradley Curve™ shows that a successful safety culture empowers people, while also improving quality, productivity and profits.

In a mature safety culture (interdependent stage), safety is truly sustainable with injury rates approaching zero. People feel empowered to act as needed to work safely. They support and challenge each other. Decisions are made at the appropriate level and people live by those decisions. The organization realizes significant business benefits through higher quality, greater productivity and increased profits.

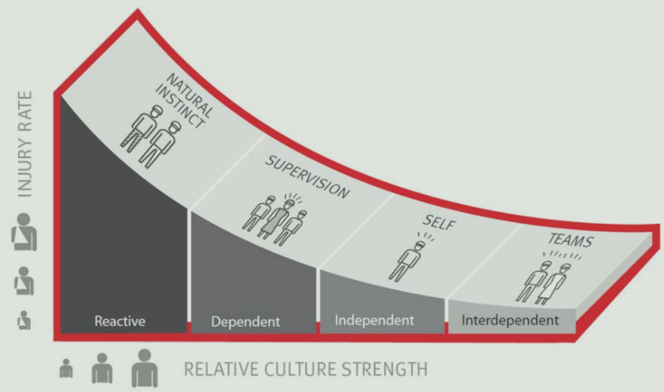
The DuPont™ Bradley Curve™, a proven proprietary system, helps clients comprehend and benchmark their journey to world-class safety performance. Since 1995, it has enabled an effective safety culture for both DuPont and its worldwide clients.

With the DuPont™ Bradley Curve™, DSS consultants help organizations in a wide range of industries around the world better understand the effectiveness of a successful safety culture —from early stages through maturity (sustainable with injury rates near zero).[2]

The DuPont™ Bradley Curve™ identifies four stages of safety culture maturity:

- *Reactive Stage*—people don't take responsibility and believe accidents will happen.
- *Dependent Stage*—people view safety as following rules. Accident rates decrease.
- *Independent Stage*—people take responsibility and believe they can make a difference with actions. Accidents reduce further.
- *Interdependent Stage*—teams feel ownership and responsibility for safety culture. They believe zero injuries is an attainable goal.

Bradley Curve



Notes

1. https://www.consultdss.com/safety-perception-survey/.
2. https://www.dupont.com/products-and-services/consulting-services-process-technologies/brands/sustainable-solutions/sub-brands/operational-risk-management/products/bradley-curve.html.

Source: DuPont (www.dupont.com).

reasons behind certain organizational behaviour patterns that lead to a failure to perceive safety issues. Having a better understanding of the safety culture of one's organization also enables the organization to anticipate internal reactions to initiatives for change.

The safety culture in a hazardous production facility is a combination of human, organizational and technical factors aimed at achieving reliable and safe working conditions and minimizing costs from accidents and outages. Company executives and managers should be aware of current safety trends in the industry. Top management needs to be involved in the formation of a safety culture at work, to overcome any inappropriate or non-supportive attitudes towards safety issues at all levels. Technologies, too, play a key role in occupational safety, including the newest technologies in protection. Creating an organization-wide safety culture also requires proper training of everyone in an organization. Increasing the awareness of all the personnel working at a hazardous production site requires that each employee understand the working conditions, the harmful effects of any hazardous materials or processes and how to protect against them.

Companies face the challenge of producing products or services within a very constrained environment using specific raw materials and operating within a given timeframe. Among the many risks a company faces—such as customers who relocate their business, shareholders who pull out, short-term profitability pressure, administrative sanctions, public opposition, technical problems and high staff turnover—the safety of its employees, its most crucial asset, should be paramount.

Dealing with risks and making compromises and trade-offs that weigh cost, lead times, quality and safety are the chief duties of top management. A safety culture approach requires deciding how much importance to assign to safety in the various compromises and trade-offs that must be made. In doing so, however, safety should not be treated separately from other priorities and challenges. Rather, safety needs to be incorporated into all decision-making, from the executive and management level to business units, operational staff and contractors.[70]

Organizations that design, manufacture, operate and oversee high-hazard technologies and products consider safety in every decision they make and in every activity. But organizations may start to drift towards risky strategies if small deviations, which once served as warning signals, gradually become normalized, or if different organizational units optimize their local goals and working practices without fully considering the impact on overall activities. Failure to share lessons, suboptimal information flow, misinterpretation of technical phenomena and corner-cutting when executing operational tasks are common findings in accident investigations.

The goal of industrial safety should be to reduce accidents, equipment failures and work injuries and establish a safe production culture among employees. But industrial activities will never be entirely risk free, and introducing new materials or technologies can bring new risks. Each change demands a thorough, independent risk analysis at the system level. It is essential to map risks at an industrial site as thoroughly as possible and take suitable risk-mitigation measures, both technical and organizational. A variety of models exist to produce a reliable risk inventory and evaluation. For hazardous materials, modelling can provide accurate predictions of the consequences of any accidents.

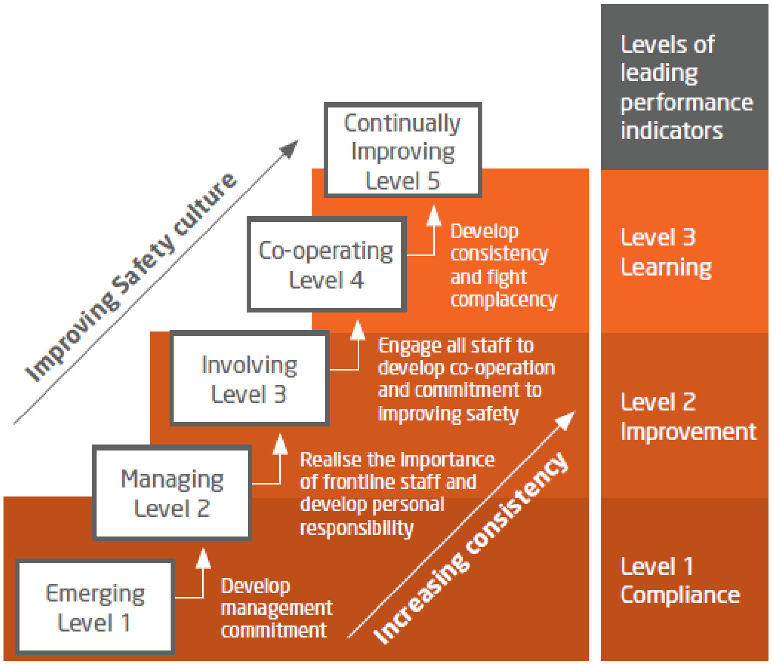
Industries prepare their own health, safety, security and environment policies and have established dedicated departments to raise awareness of the importance of industrial safety and security. In addition to increasing the safety and security of workers, equipment and buildings and of improving industrial and environmental sustainability and resilience, these policies can strengthen the innovation culture of a company. Establishing local OHS organizations that can dispense expert advice to managers and employees can also advance a strong safety culture. Organizations need to commit to systematic identification and management of hazards through appropriate risk assessments. Establishing emergency and contingency plans to deal with residual risks can also reduce threats to businesses.[71]

Similarly, government agencies need to adopt innovative approaches to improve their regulatory effectiveness and build their monitoring capacities.

In order for developing countries and the least developed countries to address industrial safety and security more efficiently, they need to build skills and capacities at all levels in both government and industry. Capacity-building programs and knowledge-sharing platforms on best practices in industrial safety can raise awareness of the injurious effects of safety mismanagement.

A five-level safety culture maturity model captures the role of safety in an organization's overall culture (Figure 3.9). In the initial phases, safety is

FIGURE 3.9
Safety culture maturity model



Source: HSE (2000).

absent from organizational culture. As the organization evolves into levels 2 and 3, safety awareness grows, but the response is still reactive. Not until an organization evolves to levels 4 and 5 does safety become an integral part of the organizational culture.

Successful OHS systems have the following elements in place:[72]

- Manager commitment to making the program work.
- Employee involvement.
- A system to identify and control hazards.
- Compliance with health and safety regulations and legislation.
- Training on safe work practices.
- Mutual respect, consideration and open communication.
- Positive safety culture.
- Continuous improvement and review of performance.

Organizations should begin with the most serious risks, those that could jeopardize their survival.

BOX 3.5
Safety culture and corporate social responsibility practices

Companies are essential partners in ensuring industrial, environmental and occupational health and safety. Japanese tire manufacturer Bridgestone, for example, has integrated safety and industrial hygiene into its corporate responsibility practices. It established a global management structure for safety and industrial hygiene in alignment with ISO 45001 and comprising a global executive committee, a global quality management committee and a working group on safety and industrial hygiene, as well as four task forces on monitoring, system structure establishment, system content standardization and metrics or key performance indicators to visualize perfect safety. As of April 2019, 53 manufacturing plants have obtained Occupational Health and Safety Assessment Series (OHSAS) 18001 certification (32 percent of 165 plants) and all facilities are adopting global standards.

Recently, and in reference to ISO 45001, Bridgestone's global safety and industrial hygiene working group established the structure of the global safety management system and standards will soon be set. In 2019, six new global safety standards were integrated into local standards. The standards include:

- Disaster prevention.
- Working at height.
- Global injury reporting.
- Lock out/tag out equipment.
- Risk assessment standards.
- Mobile equipment safety.

Training is conducted throughout the organization to meet standards as well as local regulatory requirements wherever the Bridgestone Group is operating.

Source: Bridgestone (n.d.).

That approach is more likely to lead to consensus, rally all actors and spark spillover effects on less serious risks. Having a shared awareness of the most serious risks constitutes the foundation of an organization's safety culture.

In organizations with a strong safety culture, the commitment to safety reaches from company leadership to the jobsite worker, making safety a fundamental consideration in every activity (Box 3.5). Organizations with a strong, well-integrated safety culture invest more in safety and ultimately reap greater benefits from their investments in safety than organizations with a weak safety culture or none at all.

4

MONITORING INDUSTRIAL SAFETY AND SECURITY

Government regulatory agencies need to adopt innovative approaches to boost their regulatory and monitoring effectiveness in ensuring industrial safety and security. Modern information and communication technology systems are an ideal tool for increasing monitoring quality and improving the data collection and benchmarking methods of regulatory agencies and the organizations they regulate.

Information management systems at production sites, which facilitate the collection of and timely access to accurate information, should ensure the identification, accessibility, accuracy and protection of the data that are particularly important for ensuring reliability of operations. Such systems facilitate the almost instantaneous exchange of information between locations, enabling a rapid response to accidents and accident prevention that can minimize the harmful consequences of industrial accidents.

Developments in information technology and artificial intelligence are improving industrial safety, particularly at hazardous production sites. Machines can support human decision-making, especially in high-stress situations where human decision-making may be flawed. Rapidly developing trends in artificial intelligence and artificial neural networks have the potential to increase industrial safety.

An artificial neural network is a system of simple processors (artificial neurons) connected and interacting with each other. Such processors are usually quite simple, with each processor in a network dealing only with the signals that it receives and sends to other processors. Connected to a large network with controlled interactions and learning feedback, these processors are capable of performing complex tasks. After a preliminary learning period, an artificial neural network acquires the ability to respond flexibly to changes in data entering the system and to make independent decisions and launch certain operations. Supported by a reliable computing platform, an artificial neural network can greatly improve industrial safety at a hazardous production facility.

Specialized information systems can perform certain tasks, such as monitoring the status of equipment; predicting the consequences of accidents, areas of exposure and direction of hazardous substance emissions; and calculating the risks associated with the failure of certain components—and much more. Specialized information systems enable combining all the enterprise nodes into a single system for safety monitoring and collecting data on indicators for further analysis. Multiple specialized information systems can be connected to establish a monitoring network at the regional, national or global level. On the downside, such systems can increase the risks to information security.

High-speed data transmission environments, neural networks for complex processes, and specialized information systems at the enterprise level make it possible to collect data on and evaluate key performance indicators of process safety reliability. That enables real-time analysis, which can strengthen industrial safety at hazardous production sites and other industrial facilities by identifying non-standard situations that result from the simultaneous failure of several protective barriers. Because such conditions are rare and it will take time to collect the required data, systems are needed that continuously collect, update and analyse the relevant data based on intermediate control checks.

International cooperation in monitoring industrial safety can be promoted through knowledge sharing on best practices in collecting data, benchmarking and using key performance indicators. New technologies, such as artificial intelligence and data analytics, can help governments improve industrial safety monitoring.

4.1. Key performance indicators and their applications

Assessments of safety culture can be difficult as the culture itself is complex and intangible.[73] In general, assessments must consider the organization's psychological aspects and social interactions, as well as specific structures and systems. Doing that requires a rich set of data. A safety culture assessment should incorporate multiple data collection approaches, including interviews, document analysis, observation, personnel surveys and group work. Interviews are particularly vital. Some of the most common key performance indicators of a safety culture are those that encourage employees to report unsafe conditions that hold workers accountable for securing safety and that have supervisors take a leading role.

Key performance indicators are an effective tool for assessing changes in industrial safety within an organization. These include leading indicators and lagging indicators.

Leading indicators

Leading indicators are a predictive measure related to implementing proactive measures. This type of indicator uses current conditions to predict future success. Analysis of leading indicators can be employed to improve overall occupational health and safety (OHS) management or to intervene in situations that are flagged as risky before any impacts on safety and health occur. For instance, a typical leading indicator is the percentage of workers on a building site that are wearing protective helmets. In general, the higher the compliance with the use of safety equipment, the lower the potential risk for serious accidents.

There are many other common leading indicators, including these:

- Ratio of employees with adequate OHS training.
- Frequency of site monitoring to observe unsafe behaviour.
- Frequency that OHS issues are addressed.
- Level of compliance with OHS regulations and standards.
- Ratio of managers with adequate OHS training.
- Ratio of workers with adequate OHS training.
- Ratio of management meetings at which OHS is discussed.
- Ratio of management–worker meetings at which OHS is discussed.
- Number of management visits to the shop floor where OHS is discussed.
- Ratio of business partners (suppliers, contractors) evaluated and selected on the basis of their OHS performance or a widely accepted OHS certificate.
- Number of workplace inspections or scores on workplace inspection systems, such as the ELMERI or TR observation systems.
- Frequency of observed safe or unsafe behaviours.
- Number of OHS audits performed.
- Ratio of OHS projects and activities that are finalized on time.

- Ratio of OHS suggestions or complaints on which feedback is given within two weeks to those reporting the issues.

- Number of precursors or early warnings acknowledged (events that precede serious safety problems).

- Prevalence of certain health problems (outcomes of health checks or health surveillance).

- Work Ability Index scores (predicting the likelihood of early retirement).

- Safety climate survey findings.

As this list of common leading indicators illustrates, their focus is more positive than negative, and they emphasize preventive actions related to OHS problems. Whether a key performance indicator value is considered positive or negative can depend on the context. For example, too many reports of hazardous situations can be a negative sign, but it can also be a positive sign that workers are encouraged to report potential risks.

Lagging indicators

Lagging indicators are output measures of past performance.[74] Since they are measured after the occurrence of a hazardous incident, they are generally negative indicators. A typical lagging indicator is the number of accidents on a construction site. A high number would mean that preventive measures are inadequate.

Other common lagging indicators include:

- Number of near misses (incidents with the potential to cause injury or death).

- Number of complaints of unsafe or unhealthy work environments.

- Production days lost to health-related absences.

- Fatality rates related to the work environment.

Although lagging indicators cannot assess the OHS level, they are still frequently used to determine what went wrong. They are commonly expressed in percentages, rates or absolute numbers, as in these examples:

- Lost time incident frequency due to injuries and work-related ill health (number of lost-time injuries × 1,000,000 divided by total hours worked in the period).

- Production days lost through absences for illness (percentage of total work days lost due to absences for illness, short-term sickness and long-term).

- Incidents or near misses (including those with the potential to cause injury, ill health or other loss).

- Number of complaints about unsafe or unhealthy working conditions.

- Number of early retirements.

Because people and organizations generally prefer to focus on positive feedback, some lagging indicators are framed in positive terms:

- Ratio of productive planned work days realized (for example, 97 percent productive work days compared with 3 percent of absences due to sickness).

- Number of hours worked (by the total work force) without time lost to injury.

- Number of working days since the last workplace accident.

- Employee satisfaction (survey).

Indicators that are not used very often include participative worker/management OHS committees, acknowledgment and reward for involvement in OHS activities, incentives for OHS quality and safety and health precertification requirements for all bidders and contractors.

Economic indicators

Financial resources are always limited, so companies need to use them in the most efficient way. Measuring the economic impacts of OHS may thus be important to organizations, helping them understand how much they are investing in proactive measures and what the payback is. While some preventive actions can boost production output, these indicators are difficult to measure. Still, organizations need some measure of the "return on prevention" to assess the cost-effectiveness of OHS systems and guide future investments in OHS prevention.

To control business processes, most companies use a balanced score card, which typically has four aspects: financial, customer, process and potential/learning. For a balanced OHS scorecard,[75] these four dimensions can be described as follows. An economic dimension incorporates the costs and benefits and related economic objectives associated with OHS. A strategic dimension includes the OHS objectives identified by the internal stakeholders. The OHS processes captures the contribution made to OHS behaviour and OHS itself. And the potentiality of OHS references the improved workforce (for example, more productive or creative) that can be built through OHS.[76]

It is also possible to associate costs and benefits with each key performance indicator, for example, quantifying the costs associated with time lost due to injuries. In that case, consideration should be given not only to the loss in production time but also to other associated costs, such as material damages. The ratio of employees who are absent because of illness is usually converted into financial costs as well. The result can vary because countries have different social security arrangements. Furthermore, other associated costs, such as the cost of temporary hires to replace absent workers, also need also be considered.

While there are no binding external standards for OHS reporting, the reporting framework developed by the Global Reporting Initiative is a commonly used informal standard, especially among multinational enterprises.[77] The framework includes a section on 14 labour standards and decent work indicators, which was developed with the International Labour Organization (ILO). Four of these indicators address the coverage and outcomes of OHS programmes.

Key performance indicators provide an organization with insight into OHS performance for both managers and workers. However, knowing that there are serious risks in the organization does not in itself mean that an organization will take the steps necessary to mitigate these risks. One way to build that kind of response into the system is to incorporate key performance indicators of OHS into managers' personal performance targets, particularly if they are linked to pay.[78] It is also possible to apply the same strategy to enhance safety at the team level.

Limitations of key performance indicators

Good results on key performance indicators can affect an organization's image and managers' careers and may result in reduced insurance premiums.[79] However, if a good showing on key performance indicators becomes an objective in its own right, that can generate incentives to manipulate the indicators to show positive results, which undermines their ability to improve OHS.[80] Examples include creating a culture of fear that discourages reporting accidents or taking time off for injury or illness.

Several factors should be kept in mind when trying to maintain a robust system of evaluation using key performance indicators:

- There is often a preference for measuring things that can easily be counted, such as the number of training courses or number of inspections.
- Underreporting (especially of incidents and near misses) is common, particularly where a positive OHS culture is lacking.

- The difference between a near miss and a severe accident is often a matter of luck.

- Statistical data are by definition not reliable in small enterprises.

- Positive events are usually not measured and recorded.

- An outcome measure (such as an incident) does not reflect the causes of that event.

- Numbers and percentages do not themselves imply anything about the quality of the data.

- A focus on key performance indicators may lead managers to neglect other important issues that are not measured.[81]

Risk assessments must contribute to the development of milestones and action plans and the defining of key performance measures that can track the effect of change on hazard management. This is especially important for activities that can have subtle or long-term consequences, such as a reduction in the number of maintenance personnel. Measures need to be relevant to the potential risks found by the investigations and analysis. Lead indicators, such as overtime rates, backlogs maintenance and maintenance quality, are more appropriate for assessing risk management than lag indicators. Lag indicators are also valuable, but they have limited utility in predicting future risks. Moreover, measurement should always be performed before implementation of preventive or remedial actions, in order to enable meaningful comparison of data.

Key performance indicators are critical for effective OHS management. They offer valuable feedback, inspire organizations to move forward on OHS management and are powerful communication tools. But although leading indicators hold great potential to improve OHS, standardizing them is difficult. And it should always be kept in mind that performance indicators are tools not objectives and that they simplify reality.

4.2. Industry best practices on monitoring

Boxes 4.1–4.3 offer examples of industry best practice, including the British Safety Council's Five Star Health and Safety Management System Audit, the Human Factors Assessment Model of the Offshore Safety Division of the Health and Safety Executive, and the U.S. Occupational Safety and Health Administration guidelines on monitoring.

4.3. Improving the monitoring capabilities of regulatory authorities

Risk monitoring is the systematic use of all relevant information to identify hazards and assess risks. Government agencies need innovative approaches to improving their regulatory effectiveness and for investing in building their monitoring capacities for ensuring industrial safety and security.[82] Monitoring and assessing risk at hazardous production facilities are integral parts of industrial safety management. They provide decision-makers with objective information on the state of the industrial and environmental safety of their organization, information about the most dangerous areas or processes, and recommendations on reducing risk.

The monitoring capabilities of regulatory authorities can be strengthened through supervisory support for safety and proactive safety development within an organization. The work of regulatory authorities is easier when an organization's work environment is structured in such a way that members of the organization can safely accomplish their tasks, provide feedback to regulatory authorities on the safety-conscious behaviour of employees, treat fellow employees fairly, and observe their coping skills and stress and fatigue levels. Proactive safety development implies continuously creating and implementing safety practices; monitoring the current level of safety; looking regularly for signs of weaknesses; and incorporating organizational arrangements for learning

BOX 4.1
British Safety Council Five Star Health and Safety Management System Audit

The Five Star Health and Safety Management System Audit is an evaluation of an organization's health and safety system from an independent perspective. The audit increases support for the systems and reassures companies that they are working towards best practices. The audit also provides recommendations for resolving poor practices.

The audit process is built on a business excellence model, and goes beyond Managing for Health and Safety (HSG65) to measure the progress of an organization towards achieving best practices (British Safety Council n.d., p. 4).

Eight areas of the management system are represented in the figure below.

Each audit asks the following questions (British Safety Council n.d., p. 5):

- How would you evaluate the level of effectiveness of the health and safety policies and procedures?
- Does a gap between the management system and practice exist?
- Is the organization complying with the law?
- How is the organization's performance compared with that of others?
- What is the organization not aware of?
- Is there a better way of operating?

Any business or organization can apply the audit process.

The audit also consists of the following:

- An analysis of the health and safety documentation of an organization.
- An overall assessment of the health and safety management system, and an audit on how effective the company is complying with legal requirements and best practices.
- A site inspection and discussions with employees to determine the effectiveness of the organization's implementation of the systems in place.

The findings and recommendations from the audit are provided to the organization in the form of a customized safety development plan. A generic safety plan can be designed to demonstrate how to achieve constant improvement.

Areas of the Five Star Health and Safety Audit

Source: British Safety Council (n.d.).

from experience, auditing and benchmarking the organization's safety culture.

While the importance of promoting OHS is widely recognized, it is difficult to get an accurate picture of practices on a global scale. The reliability of data collection and analysis vary over space and time, making it challenging to compare trends. Even in countries with well-established data collection systems, under-reporting is common, especially related to non-fatal occupational accidents and work-related illnesses.[83] To have reliable OHS data for analysis, countries need to implement effective OHS data collection systems (Box 4.4).[84]

Priority areas requiring attention from regulatory authorities include legal documents related to OHS, criteria for accident risk assessment and

BOX 4.2
Human Factors Assessment Model

The Human Factors Assessment Model (previously known as the Framework for Assessing Human Factors Capability) determines human factors capability as well as maturity in the offshore industry. The toolkit's aim is to identify an organization's effectiveness in managing human-related issues that add to safety. The model was generated for the Offshore Safety Division of the Health and Safety Executive for procuring and developing offshore platforms (HSE 2002, p. 1).

The assessment is applied periodically to track changes in the safety climate over time. By using the tool, sub-cultures within organizations or installations are identified.

While the tool was created specifically for the offshore industry, it can be used in other sectors. However, if the application is used in other sectors, the questionnaire items may need to be adjusted (HSE 2002).

The toolkit consists of 18 characteristics organized in accordance with the five levels of Successful Health and Safety Management" (HSE 1997). The model determines which of the five levels best describe the organization or project (HSE 2002). The five levels are:

1. Definitely not following good practice.
2. Some elements of good practice are accomplished, but not enough to be confident that the application will be consistently.
3. Good practice.
4. Good practice achieved, towards best practice.
5. Best practice.

The assessment model is useful, accessible and understandable, and without substantial background knowledge on human factors, it is easy to apply.

Source: HSE 2002.

comprehensive protection of industrial facilities (Figure 4.1).

A risk-based approach that includes four categories of hazards (extremely high, high, medium and low risk) is preferred for increasing the effectiveness of supervisory activities, as shown in Figure 4.2.

The principal ways for regulatory authorities to promote industrial safety include:

- Updating industrial safety requirements related to the state of technology applied in industrial facilities.
- Enhancing qualifications and skills of regulatory staff and employees of the organizations engaged in industrial safety.
- Introducing a risk-informed approach when organizing regulatory supervision of industrial safety (see Figure 4.2).
- Enhancing the role of compulsory insurance of the hazardous facility owner's civil liability for harm caused by accidents.
- Extending international cooperation.
- Developing accident risk analysis and assessment methods for industrial facilities.

Organizations operating hazardous production facilities should develop their own policies and guidelines on occupational safety, industrial safety and environmental protection and should create departments dedicated to raising awareness of the importance of industrial safety and protection. Implementing such measures within each organization will make it easier for regulatory bodies to monitor hazardous production facilities.

A different approach is needed in developing countries and in the least developed countries, which are more vulnerable to industrial accidents related to both natural and human causes. Lower levels of education and weaker infrastructure development, construction codes and regulations, and land planning often mean that industrial facilities are built in inappropriate geographic zones, for example, those that are prone to flooding or landslides. For developing countries and least developed countries to more effectively deal with problems of industrial and occupational safety will require training employees at all levels, in

BOX 4.3

Occupational Safety and Health Administration guidelines on monitoring

The Occupational Safety and Health Administration (OSHA) is the main regulatory body in the United States devoted to ensuring industrial safety. OSHA monitoring and evaluation guidelines cover establishing, reporting and tracking metrics that outline if the occupational health and safety program is effective. Moreover, it evaluates the overall program, both initially and periodically, to establish deficiencies and opportunities for improvement.

1. *Monitor performance and progress.* First, appropriate metrics and indicators for performance measurement have to be defined. Then, procedures have to be established and followed for collecting, analysing and reviewing performance data. Progress or performance indicators should have both leading and lagging indicators. Leading indicators reflect the potential for illnesses and injuries that have not yet happened, while lagging indicators record worker exposures and injuries that have already happened.

Guideline for accomplishment

- Establish and record measures or indicators of progress towards defined safety and health goals.
  - Record lagging indicators such as:
    - ► Amount and seriousness of injuries and illnesses.
    - ► Outputs of worker exposure monitoring.
    - ► Amount paid to compensation claims for workers.
  - Track leading indicators such as:
    - ► Degree of worker participation in program activities.
    - ► Number of hazards and close calls/near misses reported and the length of time taken to respond to reports.
    - ► Number and frequency of management walkthroughs.
    - ► Number of hazards identified during inspections.
    - ► Number of workers who have completed the required safety and health training.
    - ► Time period needed to take corrective action after the identification of a workplace hazard or the occurrence of an incident.
    - ► Compliance with planned preventive maintenance schedules.
    - ► Opinions of workers on program effectiveness.
    - ► Records of monitoring activities and results and investigate trends over time.
    - ► Share results with all workers and provide opportunities for each worker to suggest how to further improve performance.

2. *Verify the program is implemented and is operating*

The program should be evaluated at least once a year to safeguard its operation and ensure that controls identify hazards effectively and that it accelerates progress towards defined safety and health goals and objectives.

Guidelines for accomplishment

- Make sure that the program's core elements have been implemented fully and effectively.
- Make sure that the following key processes are in place and performing as intended:
  - Reports of injuries, illnesses, incidents, hazards as well as concerns.
  - Performance of workplace inspections and incident investigations.
  - Review of progress in the control of identified hazards and guarantee that hazard control measures remain effective.
  - Record and report the data needed to monitor progress and performance.

3. *Correct program deficiencies and identify opportunities to improve*

Every time a problem is diagnosed in any part of the safety and health program, it has to be acted on and dispatched to correct it and prevent its recurrence.

Guidelines for accomplishment

- Interfere to correct identified program deficiencies.
- Proactively seek input from managers, workers, supervisors and other stakeholders on the improvement of the program.
- Establish if changes in equipment, facilities, materials, key personnel or work practices trigger any requirements for changes in the program.
- Establish if the metrics and goals are still relevant and how they could be changed to trigger improvements in workplace safety and health.

Source: OSHA (2015, p. 21).

BOX 4.4
Reporting industrial safety conditions

To better identify interventions and monitor workplace health and safety, it is crucial to accurately report work-related conditions. But, for various reasons, it is common that workplace injuries and illnesses are under-reported. In research on under-reporting of work-related disorders in the workplace, Pransky et al. (1999) analysed the effects of safety incentive programs on under-reporting.

Safety incentive programs normally give rewards to supervisors and employees if there is a decrease in workplace injury rates. Hence, they may unintentionally encourage under-reporting.

To better illustrate the extent of under-reporting, as well as the causes for its occurrence, the authors used a case study. They administered questionnaires to 110 workers (who were all performing similar tasks), to several managers, and to health and safety personnel at each of three industrial operations.

The results showed that while less than 5 percent of workers officially reported a work-related injury or illness, more than 85 percent experienced work-related symptoms, 50 percent reported persistent work-related problems and 30 percent had either lost time from work or faced work restrictions due to their ailment.

Workers outlined various reasons for their lack of proper reporting, such as fear of reprisal, the belief that pain was an ordinary consequence of either work activity or ageing, lack of responsiveness of management after prior reporting and a desire to retain their jobs.

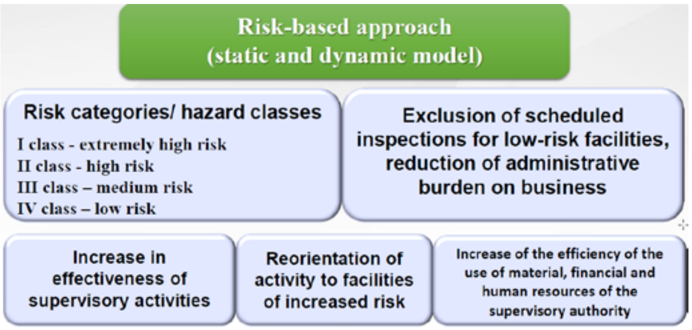
The results of the interviews with management representatives showed that there were administrative and other barriers to proper reporting, which stemmed from their desired objective of having no injuries reported and misunderstandings about requirements for recordability.

The study shows that corporate and facility safety incentives seem to have an indirect, but significantly negative influence on proper workplace reporting of injuries by workers. Worker surveys and symptom reports might be a better source, providing more valuable and timely information on risks than recorded injury logs.

Against this background, safety incentive programs should be designed in a careful way to ensure that they provide a stimulus for safety-related changes and that they similarly encourage proper reporting. A clear determination of the role of such programmes in under-reporting requires a case study of similar establishments or data gathered before and after implementing safety incentives.

Source: Pransky et al. (1999).

FIGURE 4.1
Priority areas and principal tasks



Source: Alexander Rybas, Rostechnadzor, as presented at the International Conference on Ensuring Industrial Safety, Vienna, 2019.

FIGURE 4.2
Implementation of a risk-based approach

Source: Alexander Rybas, Rostechnadzor, as presented at the International Conference on Ensuring Industrial Safety, Vienna, 2019.

both government and industry. Among the steps to take are the following:

- Building the skills and capacities of governments at all levels by designing and implementing capacity building programs and knowledge-sharing platforms for best practices on industrial safety.
- Improving data availability through better reporting and real-time data collection mechanisms.

5

UNDERSTANDING THE CONNECTION BETWEEN INDUSTRY 4.0 AND INDUSTRIAL SAFETY

The technologies emerging from the new industrial revolution (Industry 4.0) create opportunities and challenges for industrial safety. These technologies include big data, robotics, machine learning, quantum computers, artificial intelligence (AI), additive manufacturing (3D printing), the industrial internet of things (IIoT) and distributed ledger technology (DLT) or blockchain—and their integration with biotechnology, nanotechnology and cognitive, social and humanitarian sciences (known as convergent and nature-like technologies). These are also called frontier technologies because they are innovative, fast-growing, deeply interconnected and interdependent.

Rapidly advancing frontier technologies have the potential to increase productivity and competitiveness, increase energy and material resource efficiency and effectiveness, and advance the transition to a circular economy in which end-of-life products are reused, remanufactured and recycled.[85] Besides increasing production efficiency, they could provide the means to meet the increased demands of a growing population for food, land, water, energy and materials.

While emerging trends in frontier technologies are creating new opportunities in industry, they also bring new challenges for securing industrial safety. With human–machine cooperation increasing, the attendant security and safety implications need to be addressed. For example, 3D printers, which enable rapid, customizable production, also emit particles 50–700 nanometres in diameter that are capable of penetrating deep into the lungs, causing irritation, respiratory distress and changes in blood chemistry that may have detrimental cardiovascular effects.[86] The impact of new materials created by convergent technologies on health is still not well researched. And because huge quantities of data will be created, stored and analysed in real time, cybersecurity will become an even bigger challenge.

In industry, new technologies are rapidly changing the nature of production, and with that come new challenges for industrial safety and security. Inevitably, new forms of working environment will make current safety and security measures and regulations obsolete.

5.1. Industry 4.0 challenges and potential for ensuring industrial safety

New solutions and new challenges

In the traditional production environment, occupational safety and health (OHS) management is usually simple. Risk assessment procedures on all aspects of operations remain in force until the production line or equipment is changed. Situational hazards can be reduced, and production risks to employees can be prevented if the correct procedures are followed.

Advanced digital tools for collecting, storing and processing information can assist in prevention and can increase safety without putting human health at risk. New technologies offer the possibility of further safety improvement through the ability to collect data in real time and then take prompt actions before a potential hazard becomes a real one. For example, sensors and other devices can be fitted onto equipment, making it capable of detecting and reporting risks to industrial safety and security. These devices include intelligent cameras that collect digital images or video materials and then redirect them to the central control room, automatically highlighting any abnormal behaviour or activity. Digitization of the production sector means that information is available right away. Predictive analytics can optimize equipment maintenance, reducing contingency failures. This leads to crucial savings in time and money. Drones can be used for visual control and measurement. Furthermore, new forms of interaction between people and machines, in the form of virtual and augmented reality, can increase the efficiency of emergency response by enabling remote experts to engage with the problem. Wearable devices for personnel that contain embedded sensors can signal a deterioration in safety conditions. Moreover, the creation of a "data lake" that accumulates all the company information and analytical models enables data-driven decision-making at any level of management.

Along with such new solutions, Industry 4.0 also brings new challenges, such as increasing exposure to cyberattacks. Fully realizing the benefits of the Industry 4.0 paradigm shift and effectively responding to emerging challenges require a better understanding of the new safety and security risks and requirements that come with adopting new technologies. Information on industrial incidents and accidents, even non-critical ones, should be registered and accumulated in information management systems to enable a better understanding of the causes of such events and how to prevent them.

Frontier technologies and standardization

Emerging frontier technologies raise new health, safety, environmental, social and ethical issues. Industry, the research community and regulatory agencies need to be properly informed about these technologies and their potential consequences for workers, equipment and the environment.

International standards play a critical role in effectively integrating Industry 4.0 technologies into society. Among other things international standards should:

- Support the sustainable and responsible development and global dissemination of frontier technologies.
- Facilitate global trade and frontier technology–enabled systems and products.
- Support improvements in quality, safety, security, consumer and environmental protection, together with effective use of natural resources.
- Promote good practice in the production, use and disposal of materials, products and new technology-enabled systems and products.

Industry 4.0 factories will feature an unprecedented degree of automation and extensive use of the IIOT. Different systems need to be able to communicate and interact. To make this possible, interfaces must be harmonized, which requires internationally agreed norms and standards.

The key role of standardization for Industry 4.0 is reflected in ongoing international initiatives, such as:

- Various forums and consortiums of the International Organization for Standardization and the International Electrotechnical Commission (such as the World Wide Web Consortium and the Institute of Electrical and Electronics Engineers), whose work includes developing standards to ensure resource and environmental efficiency and effectiveness.
- Reference Architectural Model Industrie 4.0 (RAMI 4.0) is a German proposal for a neutral reference architecture model. The objective is to set up a comprehensive framework for the conceptual and structural design of Industry 4.0 systems, including the organization

of standard resources and the inclusion of environmental data.

The rapid emergence of new technologies increases the need to deal with evolving risks. The complexity of actors involved in cybercrimes often surpasses the ability of legislation to keep pace and poses challenges to the prosecution of such crimes. The costs are not just financial. Cyberattacks on medical services have impeded health care access, making it a vital issue for all of society. Risks need to be managed properly to ensure that technology is part of the solution and not simply the problem. [87]

Industry 4.0 has transformed manufacturing, with an unprecedented rise in data availability, computational power and connectivity. New forms of human–machine interaction are helping organizations make decisions better and faster, reducing operational costs and increasing efficiency and productivity. The ability to collect and analyse OHS data more effectively will not only ensure that smart factory workers are better protected but will ultimately enhance efficiency and productivity.

The production environment in smart factories is far more complex than in traditional factories. Smart factories are characterized by a convergence of the digital and the manufacturing, and the cyber and the physical environments. These cyber-physical systems enable the provision of data for smarter analysis and decision-making. This happens in various dimensions, such as: [88]

- Vertical integration of a production value chain's tasks and information technology infrastructure within companies, in a way that is flexible and reconfigurable (smart factories and enterprises).

- Horizontal integration of intercompany value chains and value networks (smart supply chains).

- Product life-cycle integration of digital end-to-end engineering activities throughout the production value chains.

- A simulation of production processes, depicting how parts fit together and interact, involves machines, components and people and takes place in the digital world. Physical production begins after the simulation is finalized.

When properly engaged in factories, these technological advances can enable businesses to protect workers more effectively and boost their competitiveness by reducing safety management–related costs.

Industry 4.0 can enable monitoring regulatory requirements and avoiding penalties and reputational damage that can derive from safety breaches, or neglect of regulatory requirements. Many companies have databases that record and monitor their employees' exposure to dangerous materials and help them better manage and maintain safety equipment. For instance, in the United Kingdom, small and medium-sized enterprises (SMEs) pay an average of about £40,000 a year for health and safety compliance, but could end up with a fine averaging £115,000 if found guilty of a breach.

However, much of the data are still entered manually into databases. That becomes particularly difficult to manage in large factories, making it hard to ensure that personal protective equipment and other safety devices are properly maintained, are up-to-date and compliant with standards and regulations, and are being used correctly. Moreover, with the frequent demand for efficiency, together with the increased job responsibilities put on today's safety managers, inspections of employee safety equipment may be limited to periodic factory audits or sample checks.

New digital technologies can make safety management and compliance systems smart. Embedding personal protective equipment with sensors or radio-frequency identification tags enables them to collect and transmit data—speeding data gathering and improving accuracy and efficiency. Bluetooth wireless connectivity is another advance that can improve safety management and compliance. For example, it can enable workers to connect automatically to a portable gas detector or other safety device using their smartphone. Wireless connectivity combined with the latest software and cloud technology enables safety managers to see immediately, on a computer or smartphone, which workers are using the device. Furthermore, in addition to instantaneously accessing information on a wealth of safety data, the manager can readily assess whether workers have the right training in the use of their safety equipment and whether the equipment meets regulatory requirements.

Automating safety compliance operations is not the only way in which connected technology can meet the challenges of safety compliance in today's smart factories. From automotive to aerospace industries, the move towards connected safety is already a reality in many high-risk environments, where it has demonstrated how a data-driven approach can save lives. From gas cabinets in a semiconductor plant to the wings of a Boeing 747, confined spaces are common across manufacturing and among the most hazardous environments for workers. Risks include oxygen deficiency, exposure to toxic or flammable gases, high noise levels and falls. Being able to monitor these workers' biomedical values (heart rate, body temperature, breathing rate) as well as their exposure levels in real-time can alert workers and supervisors to a potentially dangerous situation and guide emergency rescue operations if necessary.

With connectivity becoming more affordable, the connected safety infrastructure is expanding beyond high-risk environments and is being integrated into the smart factory ecosystem. The smartphone has become a versatile personal data-gathering and transmitting hub that is opening up unprecedented opportunities in safety management in both high- and low-risk environments. There are now multiple providers of industrial smartphones that offer the same ease of use as their consumer counterparts while meeting the rugged requirements of industrial environments. For example, people operating in environments with explosive potential can now use hazardous area–certified or intrinsically safe smartphones over a mobile network. A safety manager can use a smartphone from any location to access OHS data about a specific worker and intervene if corrective action is needed. The latest industrial smartphone apps also offer functionalities such as on-demand training with clear visual instructions and information on what personal protective equipment is needed for a specific task.

Additionally, safety managers can run reports on a specific population of workers, or an individual worker, to monitor exposure to hazardous substances over time. These reports can inform decisions about working patterns so that, for example, a worker's exposure levels over a particular shift can be reduced. Enabling personal protective equipment to communicate data directly with the control room also improves overall productivity and efficiency. Research conducted by the Health and Safety Executive has shown that investment in health and safety compliance results in better staff morale and motivation (HSE, 2005).

A digitally connected worker is healthier, safer and more productive. By empowering safety managers to intervene immediately to prevent dangerous situations from arising or escalating, connected safety technology can reduce worker illnesses and absences, thus cutting related financial and productivity losses for the enterprise. In the United Kingdom, for example, 25.9 million working days were lost due to work-related illness in 2018, at a cost of £9.3 billion. When a worker is absent from work for more than seven days, the employer faces costs up to £8,000 on average.

While the benefits of automating safety management processes are apparent, there are also challenges. One is how to prepare safety managers in smart factories to manage growing volumes of data effectively. Traditionally, safety managers have been responsible for managing the entire safety equipment process, from procurement through training and inspection. Increasingly however, data-driven safety monitoring and compliance processes require the involvement of a broader team, including health and data specialists to support safety managers in implementing a comprehensive safety strategy. More generally, partnerships among stakeholders, from the manufacturers of protective equipment to software and telecommunications providers, will be crucial for developing a fully connected solution to making smart factories of the future safer.

Increased cooperation between humans and robots is another important aspect of Industry 4.0. Whenever humans and robots are connected, physical security and equipment safety both need to be assessed. Employees need proper training to work with robots. Operators of robots always face some risk, since the process can be disrupted. Mechanisms are needed to protect data from manipulation and to prevent unauthorized use. Modern industrial equipment is vulnerable to cyberattack. Rarely are encryption or authentication systems used, meaning that there are gaps in security. Security must be considered as a whole, and manufacturers of equipment must ensure a safe interaction between people and machines.[89]

> Cyberattacks are an increasing threat. They can cause large economic damage and even endanger human health and lives. Cybersecurity awareness is key to ensuring that industrial safety is seen in a holistic way.

A plant operating under Industry 4.0 principles potentially has to face an intricate set of challenges, such as the need to reconfigure production areas at short notice, which involves rapid changes of tooling and may even require equipment to be moved, which can pose multiple safety challenges. Additionally, the sheer number of potential configurations that could meet requirements can entail a separate risk assessment for each. Ensuring the safety of personnel and data under a secure value-creation network further requires compliance with local, national and international regulations.

Level of risk

Which device is the right one for a particular production use depends primarily on the balance between benefits and risks. Consider the decision to move equipment. Previously, a machine would need be switched off before any action could be taken. In dynamic production environments associated with Industry 4.0, however, switching off machines is no longer necessary, thus avoiding additional warm-up times and quality issues.

In addition, many Industry 4.0-compatible technologies already incorporate safety features in their design. An example is a compatible drive, which can be used to create a machine protocol with a unique number. A potential safety issue is signalled immediately if a different protocol is used.

Also commonplace in Industry 4.0 environments is the dedicated safety protocol, such as openSAFETY, SERCOS and ProfiNet. These advances on older wire-based systems for powering down equipment, enable an uninterrupted flow of information to ensure that uptime is maximized and that powering down is used only as a last resort. An alternative is the safety zone module, which continuously verifies wires and negates the need to invest in a separate safety bus system in certain applications.[90]

Risk assessment. While such safety features are clearly beneficial, they do not preclude the need to adhere to sound health and safety practices. A risk assessment still needs to be conducted for every scenario likely to be encountered (effectively, any machine configuration that can be selected). Furthermore, operators need training to work effectively in this more dynamic environment. Applications that have always been supervised by physical guards still need the same level of protection. And no matter which manufacturing processes is adopted, the most unpredictable and vulnerable aspect of any manufacturing environment has always been and remains the people working in it. Protecting workers must remain paramount.

Even when individual system components are considered safe, risk may arise if they are combined. For example, it may be necessary to programme alternative routes for autonomous or robotic equipment that encounters an obstacle on its standard route around a facility. Organizations need to work with component suppliers and safety engineers to achieve a safety- and security-compliant production environment.[91]

In addition, significant input from ergonomics and human factors experts may be needed in the design and operation of new systems and processes.[92] Similar issues of safety and security arise with the use of robots in support of difficult and dangerous tasks in close interaction with workers.[93] Such contingencies highlight the importance of developing safety-conscious robots that recognize actions that could cause injury or threaten worker safety. For safe and effective interaction, robots need to be equipped with complex programs that allow them to reason and to understand the intentions of workers in their proximity.[94]

Connected safety is taking centre stage in today's smart factories and is enhancing worker protection as well as productivity. In smart automated factories, machines, products, tools, workers and even customers are interconnected in cyber-physical production systems. The connected sub-systems work together by exchanging information and data and striving for maximum value for each process-step along the value chain. Top drivers of this change are cloud technology, big data processing, the internet of things (embedded systems, sensors, intelligent cameras), sharing technology (crowd sourcing, crowd working), intelligent automation of tasks (robotics, artificial intelligence) and additive manufacturing (3D printing). Even low-tech personal protective equipment is becoming more intelligent and connected. Advances in connected safety technology enable businesses to protect workers more effectively while striving to achieve a competitive advantage by reducing safety management–related costs.

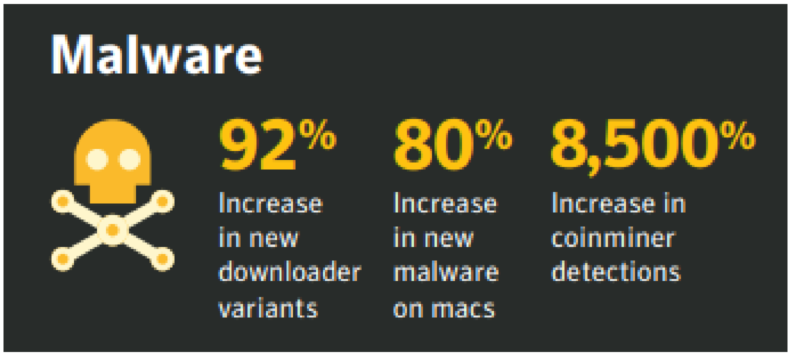
Simultaneously, new training programmes are needed that can meet changing demands. Under current business practices, sparked by Industry 4.0, workers are regularly exposed to multiple interactions and streams of information that enable them to learn better and faster.[95] To respond to the needs of an emerging sector, it is not sufficient to provide a skill set that matches prior industry requirements; rather, workers must be trained to enter into a transformed workplace. [96]

Cybersecurity risk. With the deployment of new digital technologies, smart manufacturers and digital supply networks face the operational risk of cyberattacks. Targets include safety instrumentation systems, industrial control systems and enterprise systems. According to one study, nearly half (48 percent) of UK manufacturers have experienced a cyberattack,[97] and a quarter of the attacks affected the organization financially.[98] Cybersecurity strategies are needed that are secure, resilient, constantly vigilant and fully integrated into organizational strategy from the start.

Digital security threats continue to arise from new and unexpected sources. While intellectual property is the most commonly identified motive for cyberattacks on the manufacturing sector, the motivation behind many cyberattacks is unknown.[99] In 2017, new cyberattacks ranged from the sudden spread of ransomware (WannaCry and Petya/NotPetya), which crippled networks around the world, to the swift growth in coinminers (cryptomining malware). Coinminer detections increased 8,500 percent in 2017 (Figure 5.1). Since 2017, the volume of threats has continued to rise, becoming more diverse (Figures 5.1 and 5.2). Attackers are working around the clock to find new means of attack and efficiently covering their tracks. [100] Supply chain attacks more than doubled from 2016 to 2017.

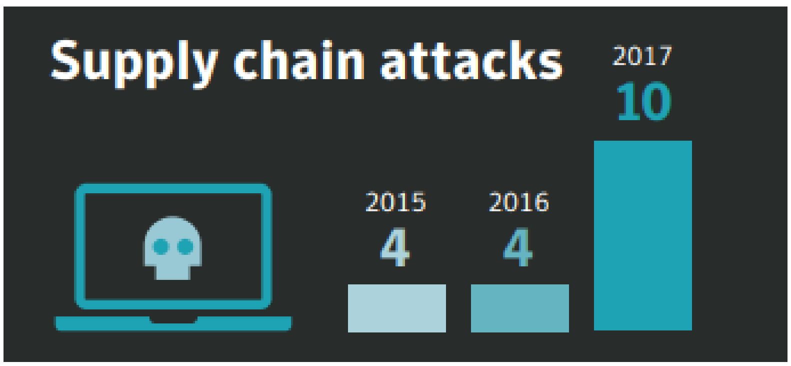
Cyberattacks have increasingly targeted operational and safety-related systems. The integration of new monitoring techniques has sparked additional challenges to various data sources, including computer and network systems (information

FIGURE 5.1
Malware attacks



Source: Symantec (2018).

FIGURE 5.2
Cyberattacks on the supply chain



Source: Symantec (2018).

technology), supervisory control and data acquisition systems and process data (pressure, flow, voltage and the like).

In predicting and avoiding cyberattacks, it is crucial to distinguish among the different types of data sources because they face different threats as well as vulnerabilities. Information technology systems include traditional personal computers, cloud storage, servers, enterprise networks, smartphones and tablets. Operational technologies add another layer of complexity to the manufacturing sector; they include industrial control systems, safety instrument systems, the IIOT and energy management systems. Consider the case of a robotic arm that rotated 180 degrees during a ping sweep even though it was on standby mode. Had an employee been standing nearby during this incident, it could have resulted in major injuries. Thus, it is important to have a deep understanding of all potential threats and vulnerabilities, as well as the operational and capital expenses for protecting employees, customers and facilities. [101]

Figure 5.3 shows the level of maturity of the implications for integrating information and operational technologies for industrial safety and security. The implications of integration of the two types of technologies are still immature for industrial safety (for information technology), and industrial security (for operational technologies).

The greater complexity of some technological advances, such as increased automation in smart factories, makes it increasingly difficult to assess risks and to predict how machines will behave in various situations. One increasingly accepted approach is machine learning, which focuses on training a machine to learn. This can be done by allowing a machine to operate in a closely supervised factory setting or by using simulations.[102] Machine learning approaches include statistical anomaly detection, classical machine learning and deep learning (for example, neural networks). A properly trained machine should be able to function safely in all the situations it might encounter in the factory. Challenges in machine learning include the explainability of results (What led to this result?), adversarial examples and causal inference (“What if” questions).

Another emerging technology is the use of a digital twin, a real-time digital replica of a physical

FIGURE 5.3
Implications of integration of IT and OT for industrial safety and security

	Information technology	Operational technology
Security	Mature	Immature
Safety	Immature	Mature

Source: International Conference on Ensuring Industrial Safety, Vienna, 2019.

device, which has applications for both safety and security.[103] Digital twins are being applied to tasks such as predictive maintenance to reduce the likelihood of catastrophic failures. The potential security applications for digital twins are vulnerability assessments, real-time attack monitoring and detection, and decision support for incident response. The technology is still immature, however, especially for security applications.

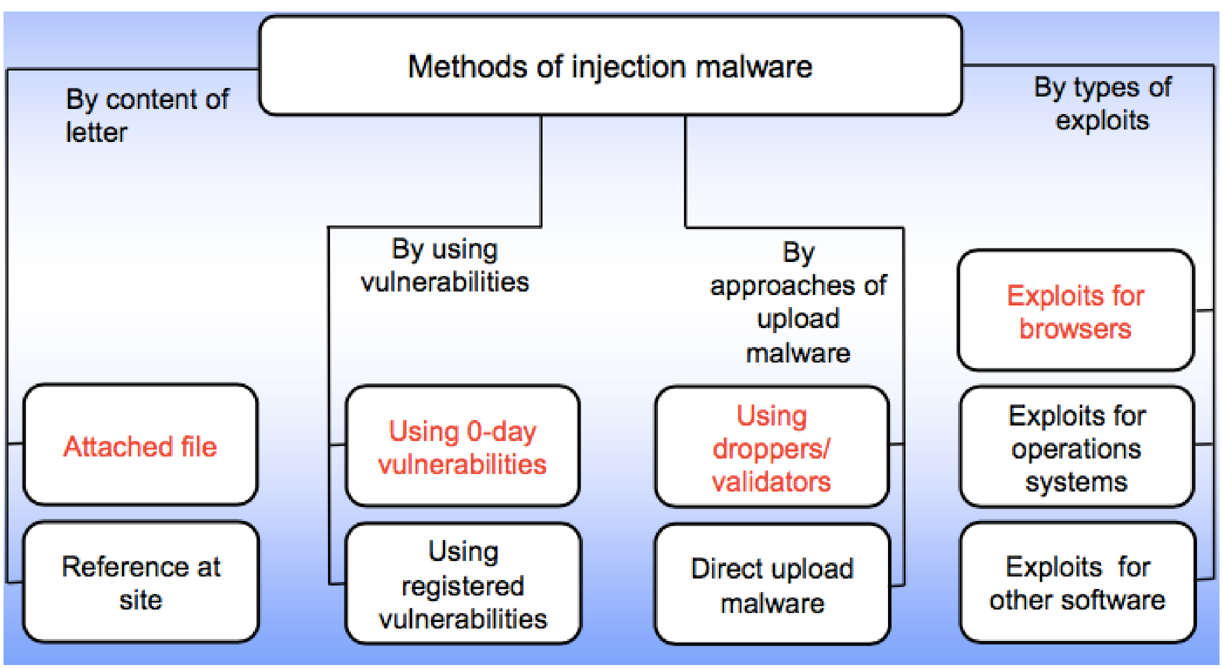
Safety and security monitoring are still not well-integrated for technology, people and processes. While machine learning can be used to obtain crucial insights into the safety and security of a system, open research challenges remain for industry safety and security.

Preparedness against spear-phishing attacks

Methods of malicious intrusion into the corporate network of an organization to extract critical information about industrial infrastructure facilities include (Figure 5.4):

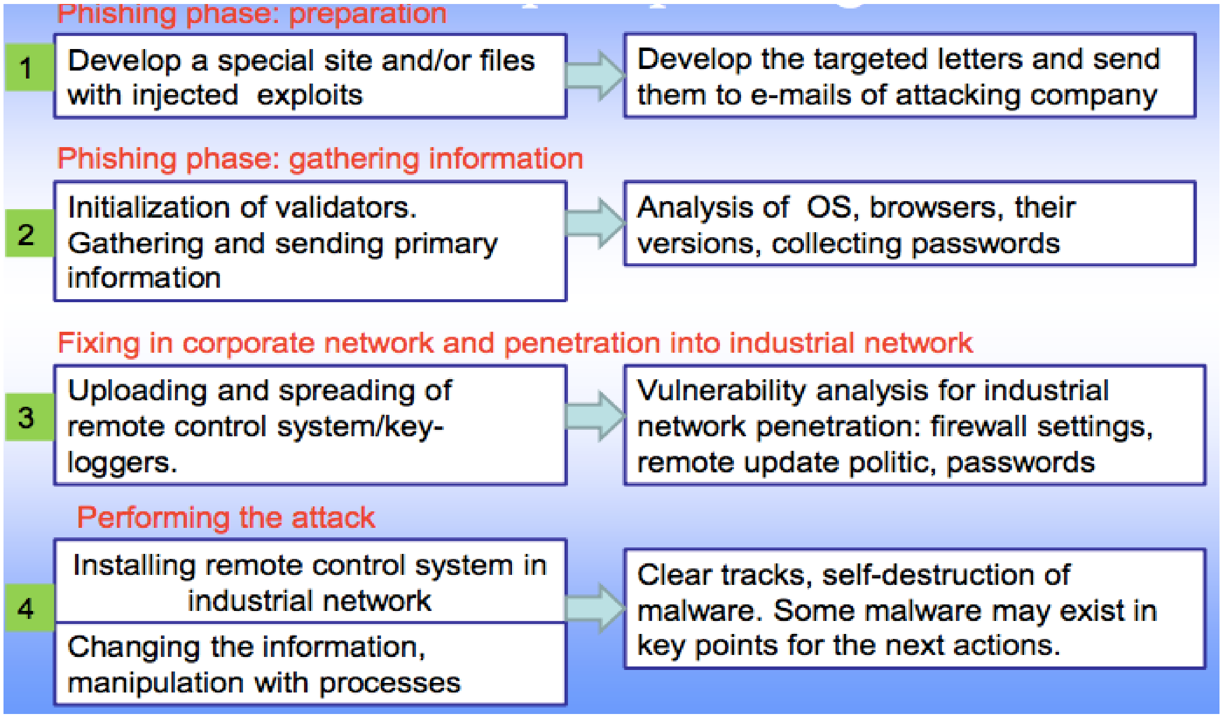
- Spear-phishing (attempts to trick specific employees into sharing sensitive security information for malicious reasons) through a link to a phishing site or an attachment. This is the most commonly used method, according to reports of leading analytical companies. Figure 5.5 shows an example of a targeted computer attack scenario using spear-phishing.
- Installing malware using removable media.
- Injecting malware into the supply chain.
- Connecting remotely using a compromised login.
- Connecting using embedded equipment, for example with a 4G modem.
- Inserting remote integration malware into source code.

FIGURE 5.4
Methods for injecting malware in a spear-phishing attack



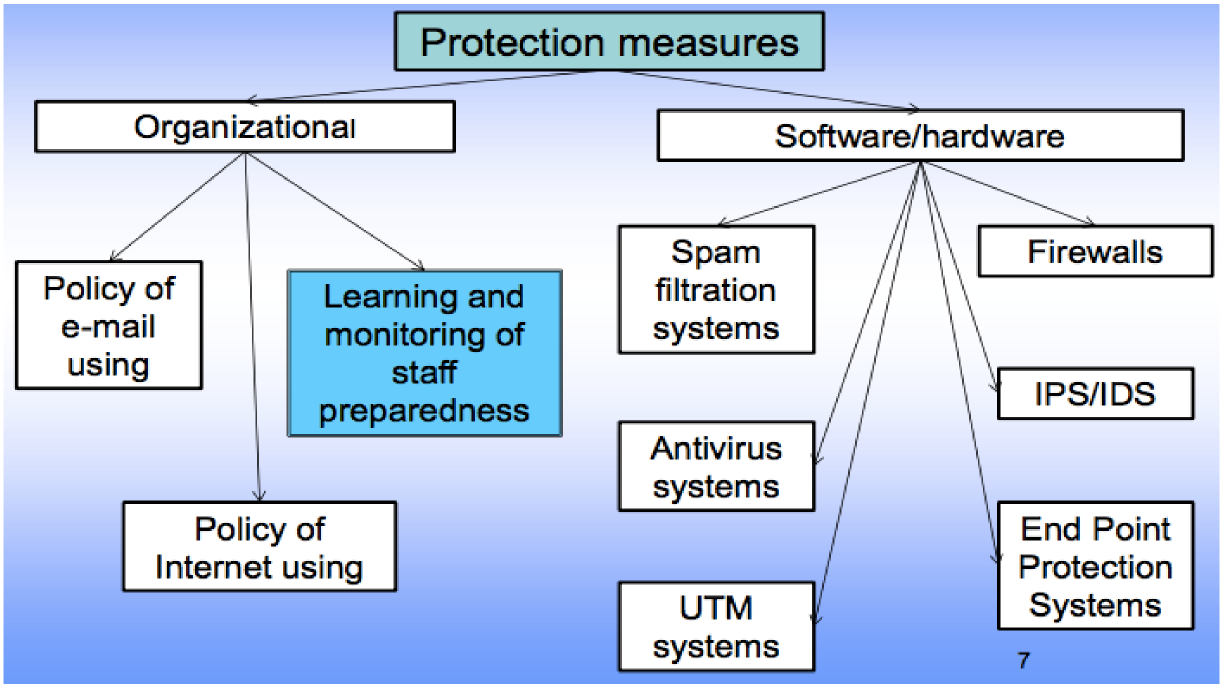
Source: Sergey Zhurin, Rosatom, as presented during International Conference on Ensuring Industrial Safety, Vienna, 2019.

FIGURE 5.5
Example of a targeted computer attack scenario using spear-phishing



Source: Sergey Zhurin, Rosatom, as presented during International Conference on Ensuring Industrial Safety, Vienna, 2019.

FIGURE 5.6
Protection measures against phishing



Source: Sergey Zhurin, Rosatom, as presented during International Conference on Ensuring Industrial Safety, Vienna, 2019.

- Connecting through traffic spoofing.

Various measures can be taken to prevent phishing. They can be differentiated by organization level and software/hardware (Figure 5.6).

One important protection measure on the organization level is training staff and monitoring staff preparedness. Readiness monitoring should include an assessment of:

- Ensuring a high percentage of trained employees among those with access to corporate email.
- Testing employees (theory and practice).
- Periodical monitoring (no more than 2–3 times a year for each employee).
- Corporate sharing of information on new threats and typical user errors when opening test phishing emails. This can, for instance, be provided on the internal portal of the organization.
- Regularly updating operating systems and email programs at workplaces.
- Installing anti-spam filters for email servers (for example to check the similarity of emails from one IP address or to set a minimum time interval between similar emails).

Moreover, it is crucial for an organization to be able to verify the integrity of code, data, contracts, transactions, messages and authorizations. After an attack, an organization needs to know which data have veracity and integrity and whether the integrity of primary data and back-ups has been breached. The integrity on a micro-level of network traffic and firmware files can be safeguarded through cryptography. At an enterprise or macro-level, an organization must ensure, for instance, that the emails of board members and executive staff related to decision-making processes have not been altered. Additionally, data integrity can be verified by checking whether service-level agreements have been adhered to or through a review of suppliers' contracts. At any point in time, whether there has been a cyberattack or not, verification of data integrity is an important task for an organization to undertake to improve security.[104]

Other recommendations for protection against spear-phishing attacks of facilities with automated process control systems include:

- Avoid physically connecting the automated process control system with external systems.
- Do not use shared media and removable storage between internal control systems and external systems.
- Minimize the likelihood of exploiting zero-day vulnerabilities by updating software.
- Separate input (for example software update) and output information streams (for example, backup).
- Delete default developer passwords.

Moreover, to optimize the choice of software, consider the following steps:

- When testing for targeted phishing, do not use cloud services.
- Use all the features of programmes for testing (for example, automatic loading of addresses, full name, operation systems information on computers).
- Systematically increase the complexity of emails while informing users about errors and results.
- Ensure the continuity of the learning and testing process.
- Consider ethical and legal risks when testing personnel, following applicable national laws.

- Use software and technical measures to protect against phishing.

- Separate corporate and industrial networks.

Effectively managing risks and exposure to cyber-attacks, which can lead to major losses for an organization, requires understanding that risks are inherent in industrial system operations. Organizations should expect the unexpected and set up efficient measures accordingly for the prevention of cyber incidents. [105]

5.2. Industrial safety and security in an Industry 4.0 work environment

With Industry 4.0 technologies expanding at an exponential rate, the implications for industrial safety and security in the work environment have risen in importance. Industry 4.0 has generated far-reaching processes of change in production, services, labour and consumption, such as:[106]

- Systems for organizing and controlling production processes have improved.

- Upstream and downstream activities are integrated deeper (internal and external).

- Research and development are increasingly multidisciplinary.

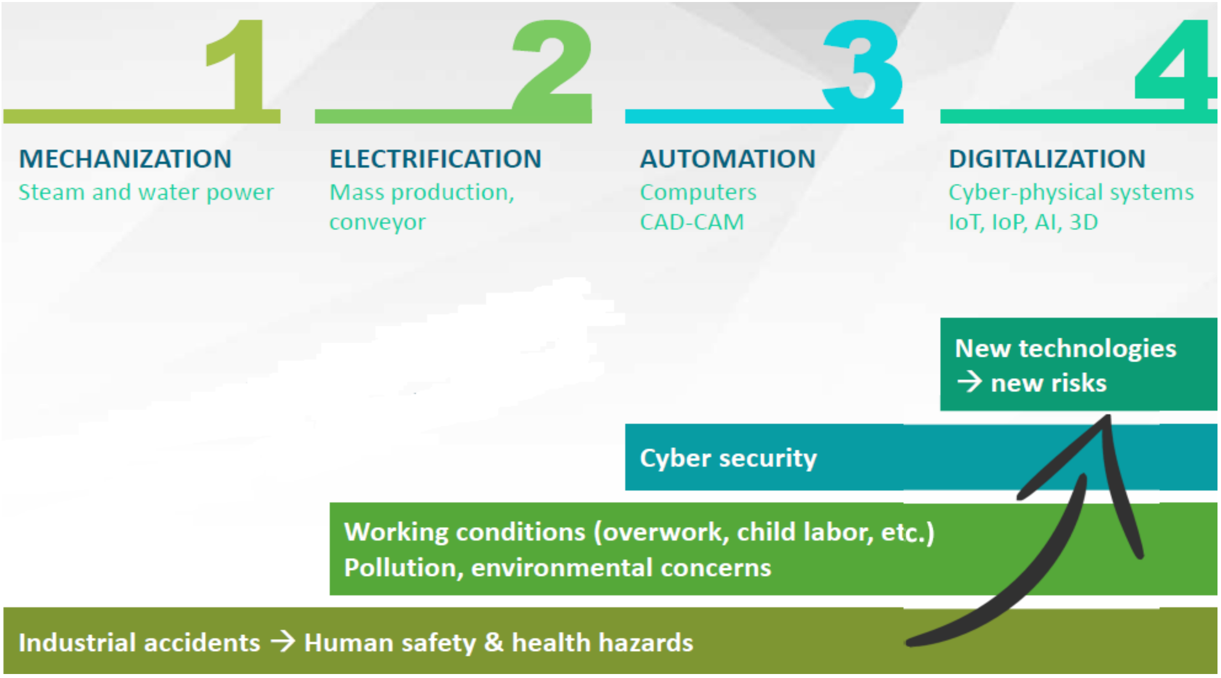
- New services and business models are individualized.

- Qualifications and competencies requirements of employees are changing.

- Education and training is becoming more important.

- New opportunities and challenges are emerging for occupational safety, health and security.

FIGURE 5.7
Industrial revolution and increasing industrial safety risks



Source: International Conference on Ensuring Industrial Safety, Vienna, 2019.

- Data protection and data security have increased in complexity.

- New forms of work organization have emerged.

There is no doubt, however, that these far-reaching changes have serious implications for industrial safety and security in a changing work environment (Figure 5.7). Although some of these implications are already apparent, their full scale and nature are still being revealed and explored and will become more apparent with the application of new technologies in the production process.[107]

While traditional, static production processes made it possible to predict hazards and risks relatively accurately, new technologies are creating more dynamic work environments that require new protective and preventive OHS measures. The changes in the work environment include:[108]

- The emergence of new work equipment and tools (which include new machine behaviour such as self-learning autonomous robots).

- The emergence of new systems of work organization and management (which also involve new worker behaviours).

- Uncertain responsibilities for safety management.

Through the expanding use of artificial intelligence in system training and control, machines are increasingly enabled to take over activities and decision-making from human workers. Along with this has come an increase in close interactions between humans and machines. These developments give rise to multiple challenges that have to be resolved in order to ensure safe operations. At a very general level, this requires:[109]

- Clearly defining how the system will behave in every situation that might be encountered throughout the operation process, in order to ensure safety.

- Implementing systems that not only behave as programmed but that also generate the evidence needed to demonstrate that behaviour.

- Understanding the kinds of events that could occur during the operation of the system, determining whether these might affect safety, and implementing any necessary mitigation measures in order to respond efficiently to any incidents that occur.

The safety and security implications of the revolutionary systems in use today cannot be adequately addressed within current regulatory frameworks and safety assurance practices. For example, unlike traditional machinery and automation, which generally kept people and machines apart, robots today often work in close proximity with their operators. That requires new forms of safety mechanisms. In addition, new systems are becoming increasingly autonomous, making it more difficult to predict the behaviour of machines and assess the safety implications. In contrast, the behaviour of traditional automated systems—for instance, the trajectory of a cutting head—is generally predictable.[110]

Apart from the changes in methods of work, Industry 4.0 involves the exchange of massive volumes of time-critical data within technological systems, emanating from an expanding number of stakeholders throughout value chains. Moreover, software plays an increasingly large role through the embeddedness of new technologies in manufacturing processes. Against this background, there is a growing range of information technology safety and security hazards related to software and network vulnerabilities.[111] Figure 5.8 shows a more detailed picture on industrial safety risks related to big data.

While other pressing issues, such as climate change and tensions in migration and international trade, often command the attention of decision-makers, industrial safety and security deserve considerable attention as well. Each year, workers are exposed to some 270 million

FIGURE 5.8
Industrial safety risks related to big data

Big data reference	Description of potential risks	Example affected industrial area
Data integration technologies	• Private data revealed by "mosaic" of supposedly anonymised datasets • Incompatible data standards and reference data causing correlation errors	• Healthcare, transport, utilities • Consumer services • World wide web
Correlation/causation difficulties	• Data analytics without e.g. proper uncertainty quantification can lead to significant false positive results (i.e. implied causalities) • Over attribution of propensities that are not necessities	• Insurance and classification industries • Healthcare • Government and policy
Collection biases	• Assuming data is predictive of a larger, unbiased cohort when it is not representative	• Economic modelling • Consumer prediction • Business analytics
Autonomous machines	• Vulnerability of machines to cyber attacks leading to unlawful control • Terrorism • Piracy	• Transport • Energy • Marine • Mining • Aerospace
Data quality	• Data insertion, updating or deleting by unauthorised individuals • Obsolete or incomplete data sets	• All

Source: Lloyd's Register Foundation (2018).

occupational accidents and 160 million work-related illnesses, resulting in global losses of $1,250 billion. Occupational injuries account for 8 percent of accidental injuries worldwide and have resulted in the loss of 10 million disability adjusted life years (healthy years of life lost due to disability or premature death). Globally, work-related deaths and illnesses account for an estimated 4 percent loss in GDP. These factors highlight that inadequate attentions to industrial safety slows economic growth overall, but especially in developing countries and the least developed countries (LDCs).

With the adoption of new Industry 4.0 technologies, the style as well as the method of safety leadership needs to be adjusted to the changing context of risks. A risk assessment of all aspects of an industrial operation, from individual components through operator touch points with equipment, can provide a guideline for action that should remain valid until production processes or equipment change. As long as correct procedures are followed, immediate hazards can be minimized and risks to operator safety can be averted.

6

CONCLUSION

6.1. The role of collective action in ensuring industrial safety

Industrial activity can have cross-border implications.[112] Pollution, spills and leaks into waterways and the air can transfer risks and hazards across borders. The impact on future generations should also be taken into account. Action needs to be taken now to ensure that natural and industrial assets are available for the next generation.

Collective action at the national and international levels is required to ensure environmental and human protection and eliminate the potentially devastating consequences of industrial accidents. At the international level, protocols, conventions and agreements are used to combat harmful transboundary effects of industrial accidents (Box 6.1). At the national and sectoral levels, ensuring environmental safety requires a systems approach to compliance with internationally agreed environmental standards. Innovative solutions and technologies are also available today for increasing the efficiency of regulatory bodies, including increased transparency through public access to the monitoring data of industrial facilities. Achieving compliance increasingly requires improving the efficiency of national regulatory authorities. Partnerships among organizations, civil society and government agencies can also help in achieving common goals.

In the context of climate change, environmental degradation and growing global interdependence, internationally coordinated actions are needed in applying accumulated knowledge, best practices and available technologies to industrial safety and reduce damage arising from natural and human-caused disasters. These collective actions can create a platform to facilitate the collection and analysis of necessary data; map hazardous areas; develop core indicators; and use information systems, information and communication technologies, and artificial intelligence for data analysis (see Box 6.2). Collective action can also enable sharing the best tools available for comparative analysis and monitoring and can facilitate communication among stakeholders for the exchange of experience, lessons learned and best practices.

BOX 6.1
Commonwealth of Independent States Agreement on Cooperation in the Field of Industrial Safety at Hazardous Production Facilities

After 18 years of concerted action by Commonwealth of Independent States (CIS) countries, the Agreement on Cooperation in the Field of Industrial Safety at Hazardous Production Facilities was signed on 28 September 2001. The agreement includes compliance with legislative and regulatory documents, and norms and standards of the CIS, the European Union, as well as with documents adopted at meetings of inter-state councils for industrial safety.

With the development and use of new technologies, new risks arise. These risks prompted discussion between CIS countries on the need to jointly develop and define new requirements for new technologies and industrial safety processes, to develop a programme for training and testing new personnel, and to conduct seminars and scientific conferences on these issues. The 16th meeting of the CIS Interstate Council on Industrial Safety was held in September 2018 in the Republic of Armenia. The agenda included the issue of implementing the technological assistance project to strengthen industrial safety in Central Asia, as well as the issue of cooperating with the UN on industrial development. It was decided to continue considering those issues at a future meeting of the Interstate Council for Industrial Safety at the CIS.

Source: Vardan Gevorgyan, Ministry of Emergency Situations of the Republic of Armenia.

BOX 6.2

Safety in the United Nations Office for Outer Space Affairs

The International Charter on Space and Major Disasters, an outcome of the United Nations Office for Outer Space Affairs (UNOOSA) and its partnerships with space agencies such as the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA), is a good example of collective action. These three agencies together cover the globe with their fleets of satellites and offer satellite imagery for development purposes. During a major emergency, they provide access to satellite information, and a network of experts interprets the images and prepares an emergency response map that shows how large an area will be affected by a disaster. Through the UN-SPIDER platform, which facilitates the use of space-based technologies for disaster management and emergency response (under the auspices of the UNOOSA), all country-level disaster management stakeholders are brought on board to coordinate data management, information exchange protocols and strategies. Space technologies are useful in collecting the data required for disaster risk reduction and for monitoring agriculture, desertification, water capture and ocean pollution. The collaboration illustrates the contribution international organizations and governments can make from the space perspective.

Source: Shirish Ravan, Senior Programme Officer, UNOOSA, International Conference on Ensuring Industrial Safety, Vienna, 2019.

BOX 6.3

Inter-Agency Coordination Group on Industrial Accidents

International organizations addressing the prevention of and preparedness for industrial accidents have been cooperating since 2011 under the umbrella of the Inter-Agency Coordination Group on Industrial Accidents, initiated by UNECE, in cooperation with OECD. The Group comprises the EU, UN Environment and the UN Environment/OCHA Joint Unit, UNDRR, UNECE, UNIDO, ILO, OECD, OPCW, WHO and other organizations. The Group regularly meets to share information on ongoing and planned activities, and identify synergies for coordinated or joint efforts. It has undertaken joint initiatives and events; discussed and provided joint inputs to global policy processes. The chairing of the Group rotates regularly among the organizations hosting its meetings.

Source: Inter-Agency Coordination Group for Industrial and Chemical Accidents 2019.

Together, international organizations should enhance their support for the development of efficient policies and regulations to develop the institutional capacity of government agencies so that they can adopt innovative approaches to improve their regulatory and monitoring functions. The regulatory function of international organizations and their activities should be aimed at the implementation of the existing legal policy instruments and standards. Furthermore, the development of additional international standards in the field of industrial safety, occupational health and safety and environmental protection could be considered.

The technical cooperation programmes and projects of international organizations should aim to augment government and industry capacity to manage industrial safety commensurate with the risks. Periodically organizing international events for the exchange of knowledge about best practices in solving industrial safety issues is a key way to do this. International organizations such as UNIDO can coordinate such efforts by convening experts, governments, professionals, academics, international organizations, representatives of industry, and civil society from different countries and regions. Forums can exchange information and discuss best practices in industrial safety and security to prevent or reduce adverse transboundary effects from industrial accidents. These meetings can also draw public attention to threats from industrial accidents and can raise awareness of emerging issues related to Industry 4.0, the circular economy and integrated safety (see Figure 6.1).

These collective activities of international organizations should be documented through reports that lay out the requirements for preventing industrial accidents, preparing for them and localizing any harmful outcomes. That would include describing procedures for informing the relevant authorities and the public about hazards, accidents and emergency incidents at industrial facilities.

Regional initiatives include the Seveso Directive, the first EU regulation calling for the creation of an interstate system of cooperation among national legislative and executive bodies in the European Union to prevent major industrial accidents. Its goal is to identify the risk of major industrial accidents at the earliest possible stages (when designing production facilities, technological processes and methods for protecting against accidents, and when planning responses to emergencies). Following the adoption of the Seveso Directive, in 1992, countries adopted the UNECE Convention on the Transboundary Effects of Industrial Accidents, following the 1986 Sandoz chemical accident at Schweizerhalle, Switzerland, which highlighted the need for trans-boundary cooperation to further regulate industrial safety beyond national boundaries. The Convention entered into force in 2000 and has 41 Parties to-date. It has been assisting countries in Eastern and South-Eastern Europe, the Caucasus and Central Asia through its Assistance and Cooperation Programme to enhance industrial safety. Other international legal and policy instruments and guidance principles exist, such as the ILO and IAEA Conventions, the OECD Guiding Principles on Chemical Accident Prevention, Preparedness and Response, just to name a few.

Given that there are several legal and policy instruments for ensuring industrial safety, international organizations should first and foremost, support their implementation at the local, national and international levels. This work should be guided by two basic principles in industrial and occupational safety: people's lives and health must be paramount in production decisions, and preventive measures should be prioritized over measures aimed at reducing the hazardous impact of an accident.

6.2. Key takeaways from the industrial safety conference

- Safety risks are specific to each industrial sector, and measures to prevent accidents and incidents must be specific as well. Moreover, the transboundary effects of a potential accident need to be considered. Collective action is required to eliminate or reduce many risks (Bernardo Calzadilla-Sarmiento, UNIDO).

- Although nuclear safety and security remain the responsibility of each country, the impacts of many accidents transcend national borders. This underlines the vital importance of effective international cooperation. International organizations are where most of that cooperation takes place, and they can help Member States fulfil their responsibility for nuclear safety and security (Juan Carlos Lentijo, IAEA).

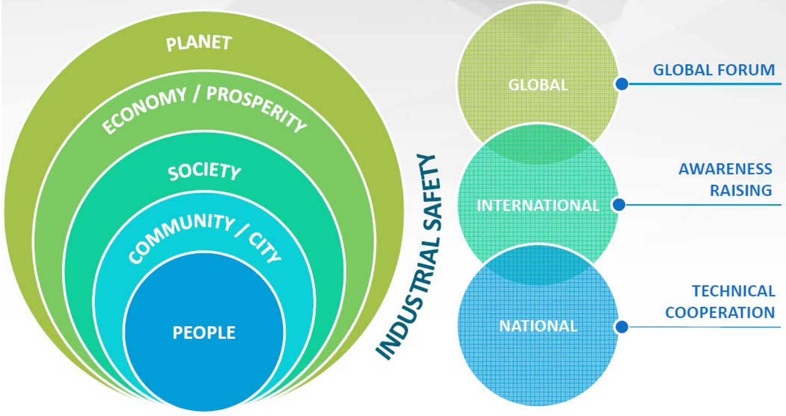
- The adoption of health and safety management systems by organizations presents opportunities for enhancing industrial and occupational safety (Kate Field, BSI).

- Countries need to cooperate and share knowledge and experience on industrial safety. The different approaches countries take to industrial safety can inform international benchmarks, which support countries in developing their own national assessment and action plans.

- The UNECE Industrial Accidents Convention fosters such cooperation for the prevention of and preparedness for industrial accidents. The Sendai Framework for Disaster Risk

FIGURE 6.1

The role of international organizations in ensuring industrial safety



Source: International Conference on Ensuring Industrial Safety, Vienna, 2019.

Reductionis a voluntary commitment for technological disaster risk reduction. The further implementation of the Convention, and efforts to meet the objective of the Sendai Framework, with respect to technological DRR, are essential to further enhance industrial safety. In this respect, understanding disaster risk, strengthening risk governance, investing in disaster risk reduction to boost resilience, and enhancing disaster preparedness are vital steps to ensure industrial safety (Franziska Hirsch, UNECE).

- An occupational health and safety culture includes eight important elements: communications, empowerment, feedback, mutual trust, problem identification, safety promotion, responsiveness and safety alertness (David Gold, Gold-Knecht Associates).

- Occupational health has a value greater than its financial costs. A country's overall health care costs fall when there are fewer accidents at the work place, and tax revenues rise because fewer people are out of work as a result of industrial accidents or illnesses. Therefore, long-term prevention plans are needed (Bob Jefferson, International SOS).

- Workers shape an organization's safety culture every day, and at the same time their health and well-being are the objectives of that safety culture. However, even companies with a well-established safety culture and safety system often have a blind spot for the health effects of dangerous situations. The Occupational Safety and Health Framework Directive (1989) lays out the basic principles for building a safety culture that is in accordance with International Labour Organization Convention 155. It takes into account technical safety as well as the prevention of ill health. Key to achieving this are regular risk assessments that also involve workers (Marian Schaapman, European Trade Union Institute).

- Target E of the Sendai Framework for Disaster Risk Reduction (DRR) calls for "substantially increasing the number of countries with national and local DRR strategies by 2020." Modern technologies, such as satellite images, can help in understanding the risks, identifying vulnerable spots, strengthening risk awareness, monitoring indicators and building resilience and an effective policy basis for action (Dr. Shirish Ravan, UNOOSA).

- Improving the regulatory framework for industrial and occupational safety can support the development of legislation and regulations governing industrial safety in hazardous production facilities. Also helpful is to formalize the criteria for classifying facilities as hazardous production facilities in accordance with international requirements and experience.

- Philanthropic foundations and charities can make a unique contribution to the culture of safety, but only by working with others. For example, Lloyd's Register Safety Accelerator, through its partner Plug and Play, connects industries that face health and safety problems with tech industry leaders and startups that have solutions to those problems (Jan Przydatek, Lloyd's Register).

- Information technology can help with safety monitoring but it comes with a raised potential for cyberattacks that we need to be aware of and accountable for (Paul Smith, Austrian Institute of Technology).

- Collective actions must be holistic, not fragmentary. Cooperation rather than competition is needed at both global and regional levels, depending on the problem. In lieu of a global government, international organizations must step in to help solve the world's pressing problems, including ensuring industrial safety (Olga Memedovic, UNIDO).

- Many stakeholders invest time and effort in improving global occupational and industrial safety and health performance, but considerable guidance is needed to ensure that their efforts are well-targeted; therefore, engagement from more countries is encouraged, for example, by participating in ISO Technical Committee 283 (Martin Cottam, Group Technical Assurance & Quality Director, Lloyd's Register/Chair—ISO/TC 283, Occupational Health & Safety Management).

- We need a pluralistic rather than individualistic approach to finding solutions that proceeds systematically and in a connected way, since risk is becoming increasingly complex to manage. Sharing experience and letting everyone benefit from the information gathered have become vital. Large investments are needed in order to work towards a unified global risk assessment scheme that would benefit everyone.

- This conference and the participation of so many people in the field reveal an interest in setting up a permanent international platform to discuss industrial safety and to achieve consensus on recommendations for the development of norms, rules and standards on a harmonized basis (Alexey Aleshin, Chairman of Rostechnadzor).

Building on the momentum created by the conference, UNIDO will organize expert group meetings laying foundations for multi-stakeholder working groups to further address industrial safety issues. The format of the working group(s) could follow the formats established by other UN agencies for other thematic areas. A steering committee that assigns study questions to working group(s) could help identify the most pressing issues at the global, regional and national levels. The steering committee and working groups, comprising experts from companies, academia and government, would come up with recommendations for follow-up activities to be elaborated by an action plan.

APPENDIX 6.1

Sustainable Development Goal (SDG) targets related to achieving industrial safety and security

Sustainable Development Goal	Targets
3 GOOD HEALTH AND WELL-BEING	**3.9** By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination. **3.A** Strengthen the implementation of the World Health Organization Framework Convention on Tobacco Control in all countries, as appropriate.
4 QUALITY EDUCATION	**4.4** By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship.
5 GENDER EQUALITY	**5.4** Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family as nationally appropriate. **5.5** Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life.
6 CLEAN WATER AND SANITATION	**6.3** By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.
8 DECENT WORK AND ECONOMIC GROWTH	**8.8** Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	**9.4** By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.
11 SUSTAINABLE CITIES AND COMMUNITIES	**11.5** By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations. **11.6** By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management. **11.B** By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels. **11.C** Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials.

Sustainable Development Goal	Targets
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	**12.4** By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.
13 CLIMATE ACTION	**13.1** Strengthen resilience and adaptive capacity to climate related hazards and natural disasters in all countries.
14 LIFE BELOW WATER	**14.1** By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	**16.6** Develop effective, accountable and transparent institutions at all levels.
17 PARTNERSHIPS FOR THE GOALS	**17.6** Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge-sharing on mutually agreed terms, including through improved coordination among existing mechanisms, in particular at the United Nations level, and through a global technology facilitation mechanism. **17.7** Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favourable terms, including on concessional and preferential terms, as mutually agreed. **17.8** Fully operationalize the technology bank and science, technology and innovation capacity-building mechanism for least developed countries by 2017 and enhance the use of enabling technology, in particular information and communications technology. **17.9** Enhance international support for implementing effective and targeted capacity-building in developing countries to support national plans to implement all the Sustainable Development Goals, including through North-South, South-South and triangular cooperation. **17.16** Enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the Sustainable Development Goals in all countries, in particular developing countries. **17.18** By 2020, enhance capacity-building support to developing countries, including for least developed countries and small island developing States, to increase significantly the availability of high-quality, timely and reliable data disaggregated by income, gender, age, race, ethnicity, migratory status, disability, geographic location and other characteristics relevant in national contexts. **17.19** By 2030, build on existing initiatives to develop measurements of progress on sustainable development that complement gross domestic product, and support statistical capacity-building in developing countries.

Source: UN (https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals).

7

ANNEXES

7.1. Conference resolution

Conference Resolution by the participants of the International Conference on Ensuring Industrial Safety: the Role of Government, Regulations, Standards and New Technologies

WHEREAS ensuring industrial safety is an important aspect for pursuing the 2030 Agenda for Sustainable Development and associated Sustainable Development Goals.

WHEREAS Industry 4.0 creates opportunities to make work environments safer and at the same time may render current industrial safety regulations obsolete due to emerging trends in technology advancements, such as big data, cloud computing, artificial intelligence, robotics, 3D printing, simulation and visualization models and convergence of technologies.

WHEREAS regulation of industrial safety needs constant adoption of innovative approaches to improve effectiveness and invest in building their monitoring capacities for ensuring industrial safety and security.

WHEREAS international cooperation is an effective tool for improving industrial safety by exchanging experience and best practices of carrying out the regulatory activities.

WHEREAS the participants of the International Conference on Ensuring Industrial Safety: The Role of Government, Regulations, Standards and New Technologies, having held productive consultations on matters of mutual interest on 30–31 May 2019 in Vienna, wish to record their intentions and objectives for cooperation.

NOW THEREFORE the participants of the International Conference on Ensuring Industrial Safety: The Role of Government, Regulations, Standards and New Technologies in Vienna declare:

1. Their intention to facilitate close cooperation between UNIDO and all concerned national stakeholders involved in ensuring industrial safety, with the objective of contributing to the achievement of the 2030 Agenda for Sustainable Development and associated Sustainable Development Goals.

2. Their intention to promote cooperation in the following areas:

- Improvement of the approaches to regulation of industrial safety and electrical power safety.

- Exchange of experience in developing regulations and standards in the field of industrial safety.

- Exchange of experience in training and examination of experts in the field of industrial safety and electrical power safety.

3. Their desire to identify and fulfil suitable projects and programmes relating to the above areas of cooperation on an annual or biennial basis in accordance with the respective policies, procedures, rules and regulations of UNIDO and depending on the availability of the necessary funds and in cooperation with UNIDO seek a possibility of establishing a specialized working group on industrial safety within its structure.

7.2. Conference structure and speakers

Conference structure

The Conference discussed the importance of ensuring industrial safety, a crucial but often overlooked aspect in pursuing the 2030 Sustainable Development Agenda. The Conference objective was to increase industrial safety and security in UNIDO client countries, thus protecting human health, industrial assets and the environment, through raised awareness and improved understanding of industrial safety and security considerations, with a special focus on the most hazardous industries—mining, chemical, oil and gas and construction.

The Conference contributed towards establishing dialogue and networking among the participants, providing opportunities for leveraging international expertise in the area of industrial safety.

Rostechnadzor, the Federal Environmental, Industrial and Nuclear Supervision Service of the Russian Federation, which has extensive expertise and a pool of leading experts in various industrial sectors relevant to industrial safety, was the main organizing counterpart involved in the Conference. The Conference also benefited from a pool of international experts.

The UNIDO Conference on Industrial Safety addressed the following issues:

- Governance of industrial safety including:
    - Role of regulations, national and international standards, compliance mechanisms, best practices of effective regulations and enforcement mechanisms.
    - Role of international agreements, protocols, conventions and guidelines.
    - Role of supervisory functions and administrative controls.
- Role of industrial safety management systems and internationally accepted safety management standards.
- Role of health, safety, security and environmental protection (HSSE) policy and provision of education and training.
- Role of key performance indicators for benchmarking industrial safety and the security of industrial sites.
- Industry 4.0, the circular economy, and industrial safety intersection: ensuring industrial safety through the application of Industry 4.0 and the circular economy.
- Role of multi-stakeholder dialogue and public-private partnerships.
- Role of international cooperation for securing industrial controls.
- Role of international organizations and particularly UNIDO's role in addressing industrial safety.

The Conference included eight interactive panel sessions addressing the following issues:

Panel Session 1 introduced the topic of the Conference through a keynote address and presentations on all aspects of industrial safety and security, including the role of risk analysis and tools and the challenges of ensuring industrial safety and security.

Panel Session 2 introduced issues on laws and regulations on industrial safety and security, including the roles of supervisory functions and administrative controls, and safety culture and international standards, agreements, protocols and conventions.

Panel Session 3 focused on the scope of industrial safety standards and their limits, and showcased management practices in industrial safety.

Panel Session 4 provided methods of building safety culture and discussed the role of signs, awareness building and training provision.

Panel Session 5 discussed monitoring industrial safety and security, and shared knowledge on best practices in collecting data, benchmarking, and using key performance indicators, as well as new technologies such as Artificial Intelligence (AI) and data analytics.

Panel Session 6 touched upon the topic on building skills and capacities at all levels of governments by designing and implementing capacity building programs and knowledge sharing platforms on best practices.

Panel Session 7 focused on the potential for Industry 4.0 to ensure industrial safety and security.

Panel Session 8 raised the topic of collective actions to ensure industrial safety and security. The session provided a wrap-up of the discussions, summarized the key issues addressed during the Conference and provided recommendations for future action.

INTERNATIONAL CONFERENCE ON

Ensuring Industrial Safety

Vienna, Austria
30 31 May 2019

The role of government, regulations, standards and new technologies

DAY 1

Industrial Safety & the 2030 Agenda for Sustainable Development and Its SDGs

Keynote Speaker
UNIDO

Dr. Bernardo Calzadilla-Sarmiento is director of the Department of Trade, Investment and Innovation at the United Nations Industrial Development Organization. Prior to this, Dr. Calzadilla was director for the Technical Assistance and Training Services at the International Organization for Standardization (ISO) as well as secretary of the ISO Policy Committee to support developing countries (ISO DEVCO). With more than 25 years of international experience as a senior quality and standards expert, his involvement includes working in Africa, Asia and Latin America.

Panelists

Franziska Hirsch is the secretary of the Convention on the Transboundary Effects of Industrial Accidents at the United Nations Economic Commission for Europe (UNECE). She has a wide range of work experience within UNECE, covering water, health, forestry, industrial safety, air pollution abatement and related energy, climate change and biodiversity issues. Prior to joining UNECE, she worked with the International Trade Centre UNCTAD/WTO, the WTO Trade and Environment Division, the European Parliament and in the private sector.

Dr. Shirish Ravan works for the United Nations Office for Outer Space Affairs. In addition to his responsibilities for the Programme on Space Applications, he is global coordinator of the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER). His previous assignments include leading the UN-SPIDER Beijing Office and the Illicit Crop Monitoring Programme of the United Nations Office on Drugs and Crime in Afghanistan. He has worked extensively with countries in Asia, the Pacific and Africa to offer technical advisory services, institutional strengthening and outreach programmes for promoting applications of space-based technologies.

Neil Walsh joined the United Nations in 2016 and is now chief of the Cybercrime and Anti-Money Laundering Section at the United Nations Office on Drugs and Crime. Prior to this, Neil served for over 15 years with the UK National Crime Agency, including long-term postings to Europol HQ in The Hague and Malta. His work involves senior-level policymaking and extensive covert operation with partners around the world, countering terrorism, cybercrime, drug trafficking, money laundering, weapons proliferation and online child sexual exploitation.

Marc Gordon is a head of the Global Risk Analysis and Reporting Unit for the United Nations Office for Disaster Risk Reduction (UNDRR). Prior to this, Marc worked as a manager in the DIPECHO South East Asia at the European Commission.

Industrial Safety Governance

Keynote Speaker

Alexander Rybas has been state secretary–Deputy chairman of the Federal Environmental, Industrial and Nuclear Supervision Service of the Russia Federation (Rostechnadzor) since 2015. Prior to this, he held different senior-level positions within the government of the Russian Federation. He also holds a Russian Federation governmental award in science and engineering as well as the Mosin Prize.

Panelists

Ardasheri Mirzozoda is deputy head of the State Supervision of Safe Work in Industry and Mining Supervision Service, Government of Tajikistan. Since 2013, he has worked at different departments within the Service, including as specialist of State Inspectorate for the Supervision of the Circulation of Explosive Materials; chief specialist of the Scientific and Technical Department; head of the State Inspectorate for the Supervision of Hazardous Production Facilities; and head of the Comprehensive Inspectorate for the Supervision of Industrial Safety in the Khatlon Region.

Shahid Mallick is the section head for the Programme and Strategy Coordination Section/Office of Safety and Security Coordination in the International Atomic Energy Agency (IAEA). He has over 30 years of experience in nuclear safety and security. Prior to his appointment at the IAEA, he served at the Pakistan Nuclear Regulatory Authority from 1994–2011 in various capacities, his last appointment as member of the Authority from 2009–2011.

Jasmina Karba works for the Ministry of the Environment and Spatial Planning of the Republic of Slovenia—Strategic and Systemic Environmental issues. She is also vice-chair of the United Nations Economic Commission for Europe, Industrial Accidents Convention. Her areas of work include the management of industrial accidents and risk, and the introduction of measurement systems for the control of the operation of establishments that work with hazardous substances and have the potential for major accidents.

Standards and Norms for Ensuring Industrial Safety and Security

Keynote Speaker

Kate Field is an expert and ambassador on occupational health and safety for the British Standards Institution. Kate started her career with the Health and Safety Executive as a regulatory inspector before moving into policy, leading initiatives to tackle health risks. Kate then moved into the private sector, working as a consultant across all industries. With a health and safety career spanning two decades, Kate has authored regulatory and technical guidance, written articles for a range of publications and is a successful global keynote speaker and presenter.

Panelists

Yanyun Wu is deputy director general in the Policy and Legislation Department of the Ministry of Emergency Management for the People's Republic of China. On numerous occasions he has participated in and been responsible for drafting, formulating and revising laws and administrative regulations regarding work safety. He has also published many works.

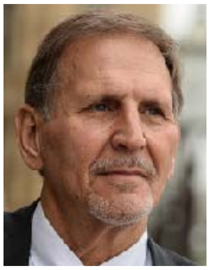
Martin Cottam is group technical assurance and quality director for Lloyd's Register. He is a member of BSI's Management Systems Expert Group, and chaired the BSI mirror committee throughout the development of ISO 45001, leading the UK delegation on the ISO 45001 project committee. Martin now chairs the ISO technical committee for occupational health and safety management (ISO/TC 283), which owns ISO 45001 and is developing additional standards and guidance on occupational health and safety management.

Michael Tooma is managing partner–Australia at the global law firm Clyde & Co where he is also global head of safety. Michael is internationally recognised as one of the leading health and safety lawyers. His practice involves proactively working with clients to achieve global safety regulatory standards and investigating and responding to incidents when and wherever they occur around the world.

DAY 2

Creating Safety and Security Culture in Industry

Keynote Speaker



Dr. David Gold is the managing director of Gold-Knecht Associates, a Swiss-based consulting firm, and chair of the IOSH, Fire Risk Management Group in Switzerland. He has over 35 years of experience in occupational health and safety, fire and travel safety, and health and security. David formerly served as a senior official of the International Labour Organization as well as a volunteer firefighter/emergency cardiac technician. As a chartered fellow of the Institution of Occupational health and safety, David is passionate about dynamically building a culture of prevention throughout the world of work.

Panelists

Marian Schaapman is head of the Health and Safety and Working Conditions Research Unit of the European Trade Union Institute and coordinator of the Workers' Interest Group of the Advisory Committee on Safety and Health at Work of the European Commission. From 2009 to 2017 she held the position of director of the Dutch Trade Union Confederation's Occupational Diseases Office. During that time, she also was a member of the Advisory Board of ETUI. She also conducted research as a labour law and policy researcher at the University of Amsterdam from 1994 to 2012.

Dr. Bob Jefferson is medical director of Occupational Health at International SOS in the United Kingdom. He was previously medical lead for Europe for IBM, head of Occupational Health for Rolls Royce plc., director of occupational health and safety for the Isle of Man Government and Deputy Director of the Medical Toxicology Centre at the University of Newcastle upon Tyne. Bob is a senior and experienced Occupational Physician also qualified in Health and Safety.

Jan Przydatek is associate director of Programmes at Lloyd's Register Foundation. He is responsible for ongoing grants, including the Assuring Autonomy International Programme, the world's first 3D-printed metal smart bridge, and a foresight review exploring the future of regulation. Jan joined the Foundation with 20 years' experience as a professional engineer in Lloyd's Register Group, having worked mainly on maritime projects that now operate safely across the globe.

Monitoring Industrial Safety and Security

Keynote Speaker

Paul Smith is a senior scientist with the Center for Digital Safety and Security at the Austrian Institute of Technology, and visiting researcher at Lancaster University. Paul's research is targeted at developing solutions to ensure the security and resilience of critical information infrastructures, including computer networks and digitalized energy systems. For each of these solutions, his interest lies in addressing the cyber-physical aspects of security and resilience. He has participated in several international research projects in this area and has published articles on various aspects that relate to his interests.

Panelists

JC Sekar is the CEO of AcuiZen Technologies, a Singapore-founded technology venture assisting people and enterprises tackle challenges resulting from the dynamic nature of work. He has over three decades of experience working with and leading teams across geographies and sectors in design, manufacturing, quality, IT, L&D, business development and operations. His most recent corporate experience was as managing director (Asia Pacific and the Middle East) for the health and safety practice of the 125-year-old U.S.-based safety science organization, Underwriters Laboratories Inc.

Lijun Wei is vice president of China Academy of Safety Science and Technology. His main fields of research include quantitative risk assessment, risk monitoring of major hazard installations, and land-use planning and risk management of chemical industrial parks. Lijun has undertaken several national scientific research and development projects in the field of industrial safety.

Michael Struckl is the division head for industrial technology at the Federal Ministry of Digital and Economic Affairs for the Government of Austria, and vice chair for the UNECE Convention of Transboundary Accidents. He is a national expert at the Joint Research Centre of the European Commission, and has authored numerous publications on risk analysis. Michael was recently awarded the title of professor by the federal president.

Blaž Markelj is assistant professor of security studies at the Faculty of Criminal Justice and Security, University of Maribor, in Slovenia. His book about mobile devices and cybersecurity was published last year in Slovenian. He has delivered several scientific and professional presentations and lectures on cybersecurity to representatives of the public sector.

Improving Regulatory Authorities Monitoring Capabilities

Keynote Speaker

Paul Logan is the director of Chemicals, Explosives and Microbiological Hazards Division for the Health and Safety Executive (HSE) of the United Kingdom. He is responsible for leading teams covering the onshore major hazards sectors, with a national network of field inspectors regulating Great Britain's onshore major hazards businesses in the chemicals, explosives and microbiology sectors. Paul also chairs the Control of Major Accident Hazards (COMAH) Competent Authorities Strategic Management Group, the Chemical and Downstream Oil Industries Forum and represents HSE on the COMAH Strategic Forum, an industry/regulator body established to drive up safety standards in the high hazard chemical and energy sectors.

Panelists

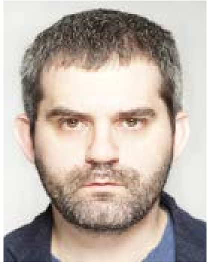
Marian Schaapman is head of the Health and Safety and Working Conditions Research Unit of the European Trade Union Institute and coordinator of the Workers' Interest Group of the Advisory Committee on Safety and Health at Work of the European Commission. From 2009 to 2017 she held the position of director of the Dutch Trade Union Confederation's Occupational Diseases Office. During that time, she also was a member of the Advisory Board of ETUI. She also conducted research as a labour law and policy researcher at the University of Amsterdam from 1994 to 2012.

Wenqi Shang is deputy director general of the Work Safety Law Enforcement Bureau in the Ministry of Emergency Management for the People's Republic of China. He has held several other senior governmental positions within the People's Republic of China.

Joaquim Pintado Nunes is officer-in-charge of the Labour Administration and Occupational Health and Safety Branch and also the lead of the Labour Administration/Labour Inspection Team in the International Labour Organization (ILO).

Industry 4.0 & Industrial Safety

Keynote Speaker



Evgeny Goncharov is head of the Industrial Control Systems Cyber Emergency Response Team at Kaspersky Lab. He has worked in software development since 1999, with 13 years' experience in the IT security industry. Evgeny joined Kaspersky Lab in 2007 as software development team lead. Since 2014, Evgeny has driven Kaspersky Lab's industrial control systems cybersecurity research, product and services development.

Panelists

Nikolaus Dürk is founder and managing director of X-Net Services. Based in Linz, Austria, X-Net Services is a network and software engineering company, and general service provider for IT-related matters. Nikolaus has been implementing innovative projects on both the national and international markets since 1999 on such topics as network engineering, development of customized software and hardware solutions and research (for example, security solutions digital heritage).

Titanilla Komenda is a scientific researcher/assistant at Fraunhofer Austria Research. With a degree in mechatronics/robotics from the University of Applied Sciences Technikum Wien (Austria), she has more than nine years of experience in planning, managing, implementing and optimizing automation solutions with robotic applications. She also teaches in higher education. Titanilla's research fields include the development and implementation of innovative solutions in the field of production and industry-related research with a focus on human-robot-collaboration.

Herbert Vitzthum is a senior consultant for Siemens AG, Austria. His responsibilities include assessing and consulting strategic industrial customers of Siemens in 21 countries of Central and Eastern Europe. Within this, he also supports and consults the top management of customers to leverage the potential of digitalization/Industry 4.0 to reach higher efficiency, and output and reduce resource consumption at the same time. Prior to working for Siemens, Herbert worked for the Austrian Ministry of Telecommunication, the European Commission, and the Internet Corporation for Assigned Names and Numbers.

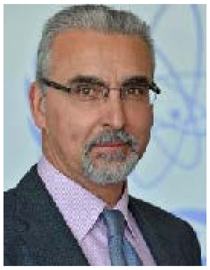
Sergey Zhurin is lead researcher and head of the Laboratory of Information Systems Development of the Federal Center of Science and High Technologies "Eleron" (Rosatom) for the Russian Federation. Prior to his appointment in 2001, he worked as a programmer at the Central Bank of the Russian Federation. He has performed extensive research on the detection of insiders, cyber-insiders, and cyber-attacks in industrial control system networks, and on the cyber and physical risks of adversaries inside domains.

Role of Collective Actions for Ensuring Industrial Safety and Security

Keynote Speaker

Dr. Olga Memedovic is deputy director of the Department of Trade, Investment and Innovation, and chief of the Business Environment, Cluster and Innovation Division within the department at the United Nations Industrial Development Organization (UNIDO). She has served at UNIDO in different capacities, as acting director for the Strategic Planning and Coordination Department; chief of the Europe and Central Asia Programme; and senior researcher in the Strategic Research and Economics Department and Private Sector Development Department. Before joining UNIDO, Dr. Memedovic served at the Netherlands Economic Institute and at the Tinbergen Institute of Erasmus University Rotterdam, Free University Amsterdam and University of Amsterdam. She has more than 37 years of international experience as a consultant and project leader for various research and technical cooperation projects in Europe, Asia, Africa and Middle East, covering formulation of strategies and polices, Global Value Chains and production networks, structural change, standards and certification, WTO rules and regulations; global governance and provision of public goods, energy efficiency and innovation and economic development.

Panelists



Juan Carlos Lentijo is deputy director general and head of the Department of Nuclear Safety and Security for the International Atomic Energy Agency (IAEA). Prior to his appointment in October 2015, he was director of the IAEA's Division of Nuclear Fuel Cycle and Waste Technology. Previously, Juan Carlos worked for the United Nations, where he held several managerial positions at the Spanish Regulatory Body, Consejo de Seguridad Nuclear. In 2017, he was awarded as engineer of the year by the Official College of Industrial Engineers of Madrid, and received a special recognition award from the Spanish Nuclear Society.

Joaquim Pintado Nunes is the officer in charge at the Labour Administration, Labour Inspection and Occupational health and safety Branch of the International Labour Organization. Prior to this he worked in the ILO's Decent Work Team and Country Office for Central and Eastern Europe as a specialist on labour administration and labour inspection. Before joining the ILO, he was the head of the Planning, Strategy and Technical Directorate of the national Authority for Working Conditions in Portugal. Joaquim worked as chief of a regional office of the national labour inspectorate, as a labour inspector and as an attorney. He was member of national inter-ministerial taskforces on labour law, occupational health and safety, industrial licencing and public administration reform. In addition, he was the national representative in two specialized committees of the European Commission, and a lecturer of occupational health and safety legislation and inspection systems. Joaquim was given two awards for excellence in public service.

Franziska Hirsch is the secretary of the Convention on the Transboundary Effects of Industrial Accidents at the United Nations Economic Commission for Europe (UNECE). She has a wide range of work experience within UNECE, covering water, health, forestry industrial safety, air pollution abatement and related energy, climate change and biodiversity issues. Prior to joining UNECE, she worked with the International Trade Centre UNCTAD/WTO, the WTO Trade and Environment Division, the European Parliament and in the private sector.

Vardan Gevorgyan is head of the National Center of Technical Safety under the Ministry of Emergency Situations of the Republic of Armenia. Vardan is a police colonel with long-standing service in various law enforcement agencies. His professional career also involves extensive experience in administrative and logistics activities in the mining sector.

Dr. Shirish Ravan works for the United Nations Office for Outer Space Affairs. In addition to his responsibilities for the Programme on Space Applications, he is global coordinator of the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER). His previous assignments include leading the UN-SPIDER Beijing Office and the Illicit Crop Monitoring Programme of the United Nations Office on Drugs and Crime in Afghanistan. He has worked extensively with countries in Asia, the Pacific and Africa to offer technical advisory services, institutional strengthening and outreach programmes for promoting applications of space-based technologies.

NOTES

1. Keynote speaker: Mr. Bernardo Calzadilla-Sarmiento, Director of the Department of Trade, Investment and Innovation ,United Nations Industrial Development Organization, UNIDO; Panelists: Ms. Franziska Hirsch, Secretary, Industrial Accidents Convention, UN Economic Commission of Europe, UNECE; Mr. Shirish Ravan, Senior Programme Officer, UN Office on Outer Space Affairs, UNOOSA; Mr. Neil J. Walsh, Chief, Cybercrime and Anti-Money Laundering Section, UN Office on Drugs and Crime, UNODC; Mr. Marc Gordon, Head of Global Risk Analysis and Reporting Unit, United Nations Office for Disaster Risk Reduction, UNDRR.
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33. Keynote speaker: Mr. Alexander Rybas, State Secretary–Deputy Chairman, Rostechnadzor; Panelists: Mr. Ardasheri Mirzozoda, Deputy Head of the State Supervision of Safe Work in Industry and Mining Supervision Service under the Government of the Republic of Tajikistan; Mr. Shahid Mallick, Section Head, Programme and Strategy Coordination Section/Office of Safety and Security Coordination, International Atomic Energy Agency, IAEA (tbc); Ms. Jasmina Karba, Ministry of Environment and Spatial Planning, Slovenia and Vice-Chair of the UNECE Industrial Accidents Convention.
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38. Keynote speaker: Ms. Kate Field, Global Champion, Health & Safety; BSI panelists: Mr. Wu Yanyun,

DDG of the Department of Policy & Regulation of Ministry of Emergency Management, PRC; Mr. Martin Cottam, Group Technical Assurance & Quality Director, Lloyd's Register/Chair—ISO/TC 283, Occupational Health & Safety Management; Mr. Michael Tooma, Managing Partner, Clyde & Co.

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51. Mr. Martin Cottam, Group Technical Assurance & Quality Director, Lloyd's Register/ Chair—ISO/TC 283, Occupational Health & Safety Management International Conference on Ensuring Industrial Safety, 2019.
52. Keynote speaker: Mr. David Gold - Managing Director, Gold-Knecht Associates, Chair, IOSH Fire Risk Management Group, Switzerland. Panelists: Ms. Marian Schaapman, Head of Health & Safety and Working Conditions Unit, European Trade Union Institute (ETUI); Dr. Robert Drysdale Jefferson, Medical Director, Occupational Health, International SOS, UK; Mr. Jan Przydatek, Associate Director of Programmes, Lloyd's Register Foundation.
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55. Vaughan 1996, p. 345.
56. NASA 1986.
57. Vaughan 1996.
58. ICSI Safety Culture Working Group 2017, p. 45.
59. Peplow 1996.
60. IAEA 1992.
61. For example, the fire at the King's Cross underground station in London (1987), the sinking of the Herald of Free Enterprise ferry (1987), the Clapham Junction rail crash (1988), the Überlingen mid-air collision (2002) and so on.
62. ICSI Safety Culture Working Group 2017, p. 45.
63. IAEA 1988, p. 21.
64. As presented by Marian Schaapman, ETUI, International Conference on Ensuring Indsutrial Safety, Vienna, 2019.
65. Daniellou, Simard and Boissières 2011.
66. American Bureau of Shipping 2012, p. 10–11. As presented by David Gold, Gold-Knecht Associates, International Conference on Ensuring Indsutrial Safety, Vienna, 2019.
67. Jones et al. 2016.
68. Agnew 2013; OSG n.d.
69. ICSI Safety Culture Working Group 2017.
70. ICSI Safety Culture Working Group 2017, p. 11.
71. Nestle n.d.
72. EazySafe n.d.
73. Keynote speaker: Mr. Paul Smith, Austrian Institute of Technology, Vienna. Panelists: Mr. JC Sekar, CEO & Co-Founder, AcuiZen Technologies, Singapore; Mr. Wei Lijun Vice President, China Academy of Safety Science & Technology; Mr. Michael Struckl, Federal Ministry of Digital and Economic Affairs, Austria and Vice-Chair of the UNECE Industrial Accidents Convention; Mr. Blaž Markelj, Professor at Faculty of Criminal Justice and Security, University of Maribor, Slovenia.
74. https://oshwiki.eu/wiki/Key_performance_indicators.
75. Köper, Möller and Zwetsloot.
76. Köper, Möller and Zwetsloot.
77. GRI 2018.
78. https://oshwiki.eu/wiki/Key_performance_indicators.
79. Ibid.
80. Frick and Zwetsloot 2007.
81. Hohnen and Hasle 2011.

82. Keynote speaker: Mr. Paul Logan, Director of Chemicals, Explosives and Microbiological Hazards Division, Health and Safety Executive (HSE), UK. Panelists: Ms. Marian Schaapman, Head of Health & Safety and Working Conditions Unit, European Trade Union Institute (ETUI); Mr. Shang Wenqi, Deputy Director-General of the Work Safety Law Enforcement Bureau of Ministry of Emergency Management, PRC; Mr Joaquim Pintado Nunes, Officer in Charge, Labour Inspection and Occupational health and safety Branch, International Labour Organization, ILO.
83. Rushton et al. 2017; Takala et al. 2017.
84. ILO 2019.
85. Keynote speaker: Mr. Evgeny Goncharov, Head of Kaspersky Lab Industrial Control Systems Cyber Emergency Response Team. Panelists: Mr. Nikolaus Dürk, CEO, X-Net; Ms. Titanilla Komenda, Researcher at Industry 4.0 Pilot Factory, Technical University Vienna & Fraunhofer Austria; Mr. Herbert Vitzthum, Senior Consultant Digitalization, Siemens, Austria; Mr. Sergey Zhurin, Lead Researcher/Head of the Laboratory of Information Systems Development of the Federal Center of Science and High Technologies "Eleron" (Rosatom), Russian Federation.
86. Underwriters Laboratories Inc. 2017.
87. Neil Walsh, UNODC, International Conference on Ensuring Industrial Safety, Vienna, 2019.
88. University of Cambridge 2019b.
89. Ms. Titanilla, Fraunhofer Austria, International Conference on Ensuring Industrial Safety.
90. Andrew Minturn is product manager at Bosch Rexroth. https://www.controlengeurope.com/article/133867/Safety-first--How-Industry-4–0-can-optimise-safety.aspx.
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94. http://iranarze.ir/wp-content/uploads/2018/09/E9588-IranArze.pdf.
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97. Make UK and AIG in 2018.
98. University of Cambridge 2019a.
99. University of Cambridge 2019a.
100. https://www2.deloitte.com/insights/us/en/focus/industry-4-0/cybersecurity-managing-risk-in-age-of-connected-production.html.
101. University of Cambridge 2019a.
102. University of Cambridge 2019c.
103. Bacchiega 2017.
104. University of Cambridge 2019a.
105. University of Cambridge 2019a.
106. https://plattformindustrie40.at/was-ist-industrie-4-0/?lang=en.
107. University of Cambridge 2019b.
108. University of Cambridge 2019b.
109. University of Cambridge 2019c.
110. University of Cambridge 2019c.
111. University of Cambridge 2019b.
112. Keynote speaker (Role of collective action): Ms. Olga Memedovic, Deputy Director of the Department of Trade, Investment and Innovation, and Chief of the Business Environment, Cluster and Innovation Division, United Nations Industrial Development Organization, UNIDO. Panelists: Mr. Juan Carlos Lentijo, Deputy Director General, Head of the Department of Nuclear Safety and Security, International Atomic Energy Agency, IAEA; Mr. Joaquim Pintado Nunes, Officer in Charge, Labour Inspection and Occupational health and safety Branch, International Labour Organization, ILO; Ms. Franziska Hirsch, Secretary, Industrial Accidents Convention, UNECE; Mr. Vardan Gevorgyan, Chairman of the Interstate Council on Industrial Safety within CIS the State non-profit organization "National Center for Technical Safety" of the Ministry of Emergency Situations of Armenia; Mr. Shirish Ravan, Senior Programme Officer, UN Office on Outer Space Affairs, UNOOSA.

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