AIDES A LA REFLEXION

Industrial safety in a changing world

Human, digital, new organizations: 10 key points for 2040

Strategic analysis group "Operator of the future"

Publication coordinated by Caroline Kamaté

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THEME

The future of safety

Les Cahiers de la sécurité industrielle

FONCSI

Fondation pour une culture de sécurité industrielle

The FonCSI, Foundation for an Industrial Safety Culture, is a public interest research foundation created in 2005, located in France.

The FonCSI finances research projects concerning potentially hazardous industrial activities and their interaction with society, and aims to encourage open dialogue with all stakeholders (regulators, associations and NGOs, local government, researchers, industrial firms, trade unions, etc.).

Its originality is the interdisciplinary nature of its activities, in France and internationally, as well as a strong commitment to innovation and to anticipating tomorrow's issues.

FonCSI's missions

- ▷ Identify and highlight new ideas and innovative practices
- ▷ Develop and fund research into industrial safety and the management of technological risks
- ▷ Contribute to the development of a research community in this area
- ▷ Transfer research results to all interested parties

FonCSI's values

- ▷ Foresight and innovation
- ▷ Knowledge and know-how
- ▷ Openness and exchange

FONCSI
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This *Cahier de la sécurité industrielle* (Industrial Safety Notebook) is the result of work carried out by the FonCSI's "Operator of the future – Work and workers in the 2040's" Strategic Analysis Scientific Group. Focused around a core of academic researchers, the group also brought together experts from FonCSI's sponsors. It met fifteen times to explore the impact of current and future global developments on industrial safety in 2040. This *Cahier* presents a summary of its work.

About the coordinator

Caroline Kamaté holds a PhD in biology. She has post-doctoral experience in academia (University Medical Center, Utrecht, Netherlands) and industry (Sanofi-Aventis, France). Her interest in scientific communication led her to join FonCSI in 2007, where she is responsible for managing research programs and disseminating the results.

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Foreword

Demographics, technological advances, globalization, industrial disaggregation, system complexity, interdependence, etc. Between now and 2030–40, the megatrends affecting our world, our societies, and therefore the world of at-risk industrial activities, will force us to revisit our approach to safety. What impact could these developments have on HSE departments and, beyond that, organizations? What new production methods, new organizations and new professional profiles will be required, against a background of anticipated technological change, a new generation of employees, and society's expectations? Why, and how should at-risk industries adapt their safety vision and actions to meet tomorrow's challenges?

Anticipating 'future safety' is, therefore, a priority for the industry in general, and for the FonCSI's sponsors in particular. That is why the FonCSI, in partnership with its sponsors (Airbus, EDF, EPSF, IRSN, Eurovia, GRTgaz, SNCF and TotalEnergies), launched a strategic analysis on the theme. This short, but ambitious research program resulted in an international academic seminar in November 2020, a conference to present the results to the Foundation's partner organizations in July 2021, and an open access book published by Springer, in the *SpringerBriefs in Safety Management* collection (Laroche, Bieder & Villena-López, 2022).

This 10-point summary of the findings, which French version has been published in May 2023 under the title "*Le monde change, la sécurité industrielle aussi*", brings the strategic analysis to a close, and paves the way for the Foundation's future work.

Toulouse, July 19, 2023

Caroline Kamaté, the Foundation for an Industrial Safety Culture (FonCSI)

Thanks

The Strategic Analysis Scientific Group (SASG) would like to thank the French and international experts who took part in the project, and contributed to the book, together with the experts who were invited to share their experience, or who took part in the prospective 'railway safety' workshop:

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Thierry Weil	Mines ParisTech, France

Content

Introduction

Context: concerns about the future of work and the industry

Science cannot predict the future, even the near future. Therefore, we must be cautious when making any bold predictions about what is to come. Nevertheless, we can make some reasonable assumptions. Notably, the fact that work and at-risk industries are likely to face enormous challenges between now and 2030–40.

Our world is undergoing radical, global change, and, on the scale of the history of societies, it is happening at an extremely rapid pace. Climate change, the ageing of the Western population, the delocalization of the value production chain, globalization, financialization, the fragmentation of organizations into interdependent networks, complexification, massive digitization, and the intense production and movement of data are transforming not only work, production and organizations, but also the attitudes of individuals and society towards them (Pariès, 2022).

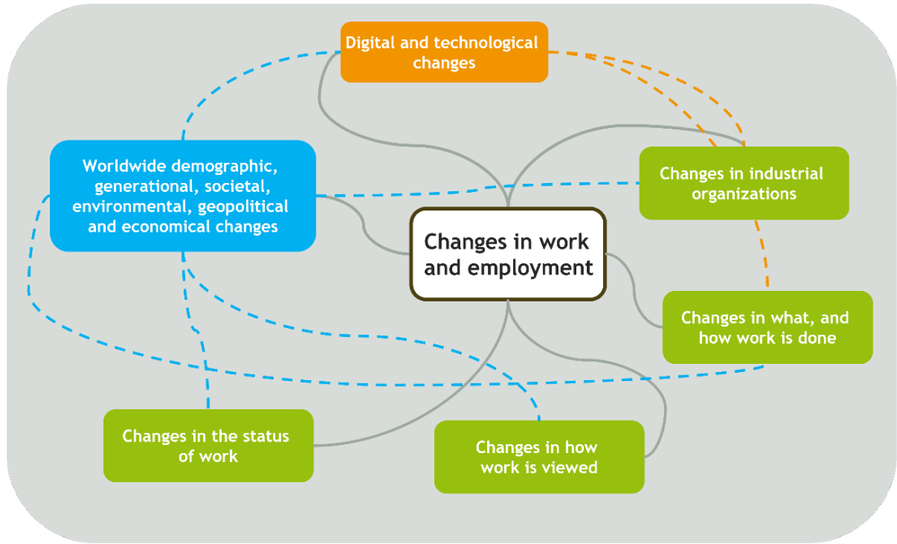

FIGURE 1: Megatrends impacting work and employment, (deeply) inspired by Gaxie & Obadia, (2019).

These major, multi-dimensional changes, often referred to as 'megatrends', are interconnected and mutually influence each other. However, for the sake of simplicity, we can distinguish 3 categories:

1. Technological changes;
2. Industrial and socio-economic changes;
3. Socio-demographic, societal, environmental and geopolitical changes.

The stakes are high not only for the industry, but also the economy and the future of societies. Consequently, the impact of these global, transformative forces on work is an issue that lies at the heart of research, and economic and political concerns at the highest levels. The topic has been the subject of numerous prospective studies, national and international plans, and reports (Fig. 2).

FIGURE 2: The future of the industry, a hot topic for numerous think-tanks, plans and programs.

What about industrial safety?

Although the impacts of automation/digitization, ageing, and socio-economic and societal changes on occupational health and safety have been widely investigated[1], we found that, rather surprisingly, technological risk and industrial safety issues have not been explored to the same extent in prospective studies. Only a few publications, meetings or organizations have discussed the influence of major current and future changes on the safety of high-risk industrial activities.

However, these megatrends, which bring with them profound changes in terms of jobs, individual and collective skills, how work is organized and carried out, the relationship with work, societal expectations, etc., raise questions about safety challenges that should not be overlooked by high-risk industries.

Against this background, and the concerns raised by its industrial sponsors (transport and energy industries, supervisory authorities and other bodies), the FonCSI launched, in 2019, a strategic analysis on the topic of 'The operator of the future – Work and workers in the 2040's[2] .

The "operator of the future" strategic analysis in a nutshell

The aim of the analysis was to carry out a high-quality research study in a relatively short timeframe, and to create a continuum between research, innovation and industry. It comprised 3 main stages, described below (Fig. 3):

1. The state of the art: the first stage consisted of an overview of the literature, developing an analytical plan, reformulating the problem, and identifying international experts who could contribute to the theme. The end of this first phase was marked by a two-day international academic seminar with some of the experts identified by the SASG.
2. The second stage consisted of developing an understanding of the current situation, and a comparison with industrial practices: this stage enabled us to analyze the contributions from experts, and to compare this material with industrial practices. It concluded with a half-day seminar with industrial partners, and was designed as an opportunity to learn lessons from the analysis regarding concepts and practices.

1. See (Marsot, et al., 2021; Aublet-Cuvelier, Hery, & Malenfer, 2022; INRS, 2016; ILO, 2019);.
2. More usually referred to as 'The Operator of the Future'.

3. The third stage involved the promotion and dissemination of the results of the analysis: an open access Springer book reporting on the work that was carried out, and the debates that were held during the academic seminar. As a follow-up to the seminar, a summary to be published in the FonCSI's *Industrial Safety Notebooks* collection, along with (potentially) other publications[3] were also planned.

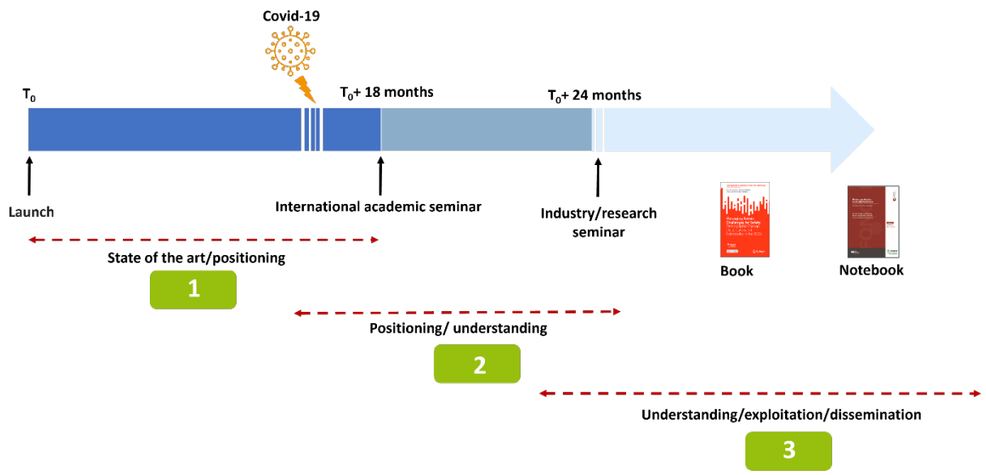

FIGURE 3: The phases making up the strategic analysis.

As the diagram shows, the timing of the analysis did not escape the impact of the Covid-19 pandemic, which hit the world in 2020.

The Strategic Analysis Scientific Group

The project was led by the FonCSI's Strategic Analysis Scientific Group (SASG). This group is made up of a permanent core of researchers who take part in all of the strategic analyses carried out by the FonCSI:

- Corinne Bieder, Enac;
- Hervé Laroche, ESCP Business School;
- Jesús Villena López, Ergotec;

and the Foundation's senior managers:

- René Amalberti, Director;
- Jean Pariès, Scientific Director FonCSI/Icsi[4].

The small committee was complemented by experts from the industry and other FonCSI partner organizations that are widely recognized for their work in the field of safety and risk:

- Florence Reuzeau, Airbus;
- Raluca Ciobanu, EDF;
- Laurent Cebulski & Bruno Dember,
- French Rail Safety Authority (EPSF);

FIGURE 4:
Sponsors who took part in the strategic analysis.

3. This follows the pattern established by previous strategic analyses. A summary of a railway workshop has been published (FonCSI, 2021) and another *Industrial Safety Notebook* will be published shortly (Bieder, Bringing together humanity and technology in context, forthcoming).
4. The Institute for an Industrial Safety Culture, an association with which the FonCSI has a historical link: https://www.icsi-eu.org.

- Franck Ollivier, Eurovia;
- Nicolas Engler & Thierry Escaffre, GRTgaz;
- Dounia Tazi, Icsi;
- Alexandre Largier & Tania Navarro Rodriguez, French Institute for Radiation Protection and Nuclear Safety (IRSN);
- Stella Duvenci-Langa & Cyril Cappi, French National Railway Company (SNCF).

International experts

For this strategic analysis, the disruption caused by the Covid-19 crisis meant that we could not hold a residential academic seminar. The seven international experts identified by the SASG were therefore invited to take part in a remote seminar in November 2020. This was an opportunity for them to present their work to the SASG, compare their points of view, and propose avenues for improvement:

- John Allspaw, Adaptive Capacity Labs, USA;
- Stian Antonsen, Norwegian University of Science and Technology, Norway;
- Michael Baram, Boston University, USA;
- Flore Barcellini, Cnam, France;
- Gérard de Boisboissel, Saint-Cyr Military Academy Research Center, France;
- Steven Shorrock, Eurocontrol, UK, France;
- Akira Tosé, Niigata University, Japan.

This Industrial Safety Notebook

Objectives

During the strategic analysis, the SASG focused on the potential impact of the above megatrends on three key dimensions of safety:

1. The nature of risks and safety models;
2. Safety culture;
3. Safety governance.

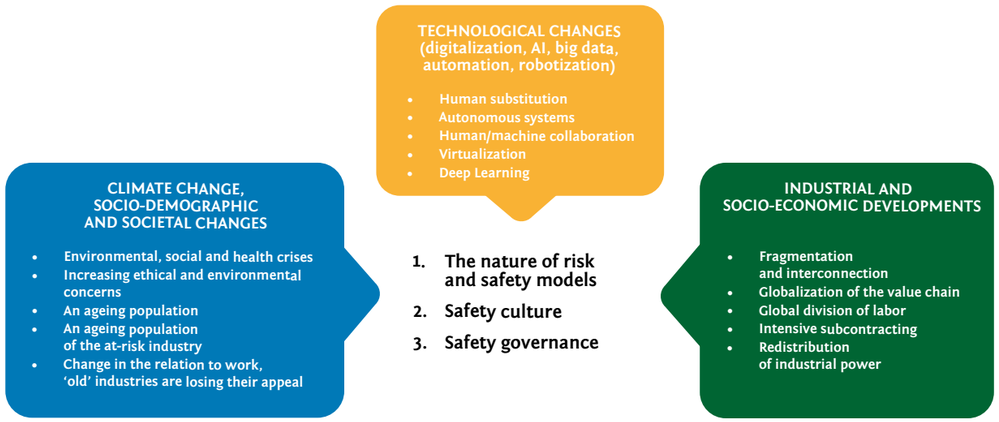

FIGURE 5: The global megatrends impacting the key dimensions of safety.

The SASG investigated some of the safety issues that emerge when the high-risk industry is viewed through the prism of megatrends. It focused on vulnerabilities that could emerge or be strengthened in the future, and potential threats to safety culture(s), and put forward some thoughts on how safety governance could

change. These are just a few of the major issues that, from the Group's point of view, should be addressed by decision-makers in the world of high-risk activities, as they come face-to-face with a complex, unstable and uncertain future.

Structure

This *Cahier* is structured into 2 parts, covering a total of 10 key points:

- Part one : 7 '**safety' challenges** brought on by global change;
- Part two: **3 approaches** to industrial safety for 2030–40.

To find out more

Further reading

We invite the interested reader to refer to the bibliography included at the end of this document, and, in particular, to other outcomes of this Strategic Analysis:

- the open access book published by Springer in October 2022 (Laroche, Bieder, & Villena-López, 2022);
- the summary of the rail workshop published in May 2021, free to download from the Foundation's website;
- a second *Industrial Safety Notebook* prepared in the context of this strategic analysis, focused on people and technology (Bieder, forthcoming).

Future work

Some of the issues raised by this strategic analysis will be the subject of more in-depth studies in the context of the FonCSI's 2023–2027 program (FonCSI 4). The agenda already includes the following strategic analyses:

- Safety practices in the era of the digital transition;
- Skills and careers in 2040;
- Safety governance in the broader context of sustainability and social responsibility;
- Integrating industrial risks into ESG reporting

Part one

7 safety challenges in a changing world

1

The world's increasing complexity, uncertainty and instability will impact safety

Ongoing technological acceleration, along with the steady increase in computing power, the flood of data, and the prospect of digital twins becoming normal, makes it reasonable to expect an even-greater capacity for anticipation, which will improve reliability and safety within the known operating range of systems. At the same time, the technological developments that we are currently witnessing go hand-in-hand with significant gains in industrial reliability and safety, which is, of course, one of their objectives. Nevertheless, it is also important to consider the side effects.

First, the massive storage and movement of data in a world that is more open and connected (notably in the form of sensors, transmission capacities and algorithms that can be easily accessed), exposes high-risk industries, like any other industry, to cyberthreats. It is not difficult to imagine the damaging consequences of a cyberattack that degrades safety in the vitally-important energy or transport sectors, for example. At another level, when the capabilities (e.g., communication algorithms or satellites) of another country are used to operate a high-risk system, geopolitical conditions can have a direct impact on how that system operates.

Secondly, new technologies will not be able to 'do everything, right now'. For example, in high-risk organizations, artificial intelligence (AI) applications remain limited, not least for safety reasons[5] (Antonsen, 2022; Bieder & Villena López, 2022). It is therefore more likely that, in the future, legacy and advanced technologies will coexist—and this cohabitation raises questions about safety.

Finally, significant technological improvements, along with other long-term trends such as the rise of artificial intelligence, increasing interconnection and networks, more interactions between different stakeholders (companies, regulators, public authorities, NGOs, the media, citizens, etc.) comes at the price of increased systemic, legal and regulatory complexity, along with a redistribution of roles and responsibilities that generate further vulnerabilities and uncertainties. One very important consequence of systemic complexification is that systems that are increasingly safe in normal conditions (i.e., under known operating conditions), will behave in ways that are increasingly difficult to predict under exceptional conditions. This could lead to catastrophe. Because, although the respective properties of the components of a complex system are generally well-known, the overall behavior of a complex system is not governed by these individual properties, but *interactions and interdependencies* between these same components. For example, just the introduction of redundancy (e.g., two pumps rather than one) means that the reliability of one component (one pump) becomes a second-order contributor to overall reliability, as the dominant factor becomes common failure modes. And these interactions lead to (both in exceptional conditions *and* in the context of nominal operation), unexpected, unpredictable and non-linear 'emergent' behaviors (the butterfly effect, cascades, avalanches, resonance, etc.), some of which may prove to be catastrophic. The future could, therefore, see an increase in the risk of 'normal' accidents, in the sense of Perrow (1999), in other words, accidents that are not linked to unwanted behavior, but to 'normal' and unforeseen system behavior. New vulnerabilities are likely to emerge, while social demands for safety are likely to increase.

Key Point

Challenge 1: The world's increasing complexity, uncertainty and instability will impact safety

Increasing computing capacity, and massive data mean:

- greater reliability and safety in the context of known system operations;
- more open, interconnected systems, cohabitation of old and new technologies, increased complexity, etc.;
- new vulnerabilities, unpredictable and potentially catastrophic residual risk.

5. Due to a lack of confidence, or a lack of proof of the inability to damage critical systems.

2

The unique characteristics of human operators will always contribute to safety

The huge acceleration in technology, particularly AI, raises questions about the role of humans, not only with respect to their unique management capabilities, but also in the domain of safety governance (Bieder, forthcoming).

Firstly, despite the massive automation and growing autonomy of systems, linked to the rise of self-learning AI technologies, humans must still intervene in most operations. For example, in the military sector, which is particularly advanced in terms of autonomous technologies (De Boisboissel, 2022), humans remain indispensable. Despite the ability to delegate tasks to machines, operators have the best understanding of a real-life, evolving situation; moreover, leaders must always retain control over autonomous systems, and remain responsible for decision-making. Furthermore, humans are the most adaptable component in a complex, rapidly-evolving and unpredictable system, which means that, in many cases, they are able to continue operating in the face of failures (Cook, 2020). The rise of new technologies, in particular AI, which can modify its behavior as it learns, fosters the emergence of new uncertainties. Operating safely in these more uncertain conditions calls for, more than ever, a human being. For example, Shorrock (2022), studied healthcare workers during the Covid crisis, and showed that it was their ability to analyze and understand the reality of what was happening in the field, together with their imagination and collective intelligence, that enabled these professionals to address the challenges they encountered, and avoid, as far as possible, harm to both patients and their carers. Thus, anticipation, imagination, collective intelligence, adaptability, diversity, insight, creativity, empathy, and wisdom, appear to be human-specific characteristics that are key to safety (Dekker, 2015) and will doubtless remain so for a long time to come.

Challenge 2: The unique characteristics of human operators will always contribute to safety

Key Point

Human beings:

- retain control over autonomous systems;
- retain responsibility for decision-making;
- are able to adapt to rapidly changing, unpredictable situations.

The values and characteristics specific to human beings (ethics, morality, creativity, empathy, collective intelligence, adaptability, etc.) are essential for safety.

3

The ‘skills challenge’, including safety skills, will become significant

While the first three industrial revolutions correspond, respectively, to the advent of the steam engine, electricity, and personal computers, the period we are currently living in, sometimes called the fourth technological revolution, refers to the creation and deployment of new technologies that combine physical, digital and organic worlds, which impact the whole range of disciplines, economies and industries (Balliester & Elsheiki, 2018).

This new era is one of information and communication technologies, along with others such as AI, automation, robotization, autonomous vehicles, the Internet of Things, etc. Although robotization and automation are not new, the pace of their development, in combination with digitization and AI, has accelerated considerably, and it is reasonable to think that this will continue in the near future. A major challenge for the industry is the adoption of these technologies in order to remain competitive—a huge skills challenge. Inevitably, these changes will mean that some jobs will disappear. However, we should not forget that past assessments have tended to overestimate the volume of jobs that would be eliminated by the first wave of automation (Frey & Osborne, 2013). While some jobs will disappear, many more are likely to be created (NESTA, 2017). Rather than decreasing the number of jobs, the momentum driving this technological revolution (in the context of other megatrends such as an ageing population, the development of the green economy, a rapid fall in the appeal of certain industrial sectors, etc.) is more likely to transform jobs. And Western countries may not face a shortage of jobs, but a shortage of skilled labor. The biggest reservoirs of young talent will be in Asia, and while net migration will partly compensate for the shortage of highly-skilled workers, around 1 billion people worldwide (a third of the current workforce) will need to be retrained by 2025 (Zahidi, 2020). Retraining workers in new technologies will still be a challenge in 2030. Fifty percent of the European workforce will need to be retrained, but the current model is too slow and poorly-suited to meeting demand (Balliester & Elsheiki, 2018). Job polarization could accelerate, with projections showing a decline in semi-skilled jobs to the benefit of, on the one hand, a growing need for high-skilled workers and, on the other hand, an increase in lower-skilled, lower-paid jobs.

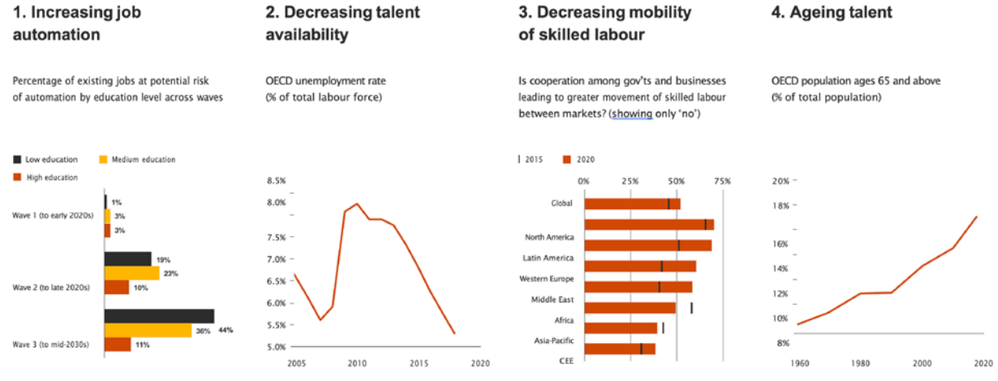

FIGURE 6: Will robots really steal our jobs? An international analysis (PWC, 2020).

Secondly, the cohabitation of old and new technologies, referred to under point 1, clearly illustrates another aspect of the skills challenge that the high-risk industry already faces. Not only does it highlight the need to adapt the retraining or hiring of personnel to cope with the shortage of digital skills, but it also raises the question of how to transfer safety skills and know-how from older workers, who are the last to use these legacy systems and understand their fine details, to the younger generation.

Finally, as illustrated during the workshop on safety in the future railway world, today's digital systems are relatively generic, and have been developed by people who do not understand well the physical systems that are in place, or their operational characteristics (FonCSI, 2021). More generally, the disconnect between high-risk industries and the digital industry leads to the 'disembodiment' of the design of AI systems (Bieder, forthcoming). Thus, within high-risk organizations, there will be fewer and fewer people with the skills needed to verify and approve digital technologies, increasing the likelihood that the job will be delegated to a third party. The situation will be all the more critical if it is the case that regulations differ between the country where algorithms are developed, and the country in which they are implemented, raising, in turn, serious questions regarding liability (Bieder, forthcoming).

Challenge 3: The 'skills challenge', including safety skills, will become significant

Key Point

Employment trends in France and Europe:

- more transformation than elimination;
- a shortage of skilled labor rather than jobs;
- polarization.

The skills challenge in the safety domain:

- the training model will struggle to (re)train a large part of the workforce in new technologies;
- it will be difficult to transfer the safety skills and know-how of older workers familiar with legacy systems to younger generations;
- the lack of computer skills in at-risk companies will lead to external third parties being delegated with the task of verifying and certifying digital technologies.

4

Differences in organizational and generational culture will test safety culture

Current global developments, such as socio-demographic changes, the accelerating fragmentation and interconnection of organizations, and the widespread use of outsourcing, are challenging the notion of safety culture, both within and between organizations (Bieder & Villena López, 2022). Changing work patterns are increasing fragmentation within teams and other occupational groups. Consequently, building and maintaining a safety culture within communities of practice implies revisiting modes of cooperation, collaboration and communication.

Like Japan, most European countries will soon be faced with an ageing workforce. Raising the age of retirement should go hand-in-hand with serious upstream consideration of a strategy to manage long careers, as this can have an impact on both safety, and the long-term success of the company's safety culture. For example, to prevent senior management positions being monopolized by older employees, and thereby excluding the next generation, Japan is experimenting with operational solutions that involve inviting older employees to become trainers at the end of their careers (Tosé & Tazi, 2022). However, the transposition of such an approach to Europe, and France in particular, remains hypothetical to say the least. An ageing workforce also means a widening of the age range of a company's workforce. One consequence is a greater diversity of skills and competencies, and differences in how the job and the company are viewed among employees who must work together. This may make it more difficult to develop and maintain a shared safety culture (Bieder & Villena López, 2022). Building a long-term safety culture can also be difficult in fragmented, diverse organizations, as objectives may differ or even oppose each other, there is less sense of belonging to an organization or an industry, and labor relations may be deteriorating, including in the domain of safety (Bieder & Villena López, 2022).

The fragile financial situation of several key actors in French industry could have a major impact between now and 2030, notably, a change in ownership, and the transfer of executive committees abroad. These changes could lead to a significant cultural shift, in particular, an understanding of day-to-day safety management that is very different from current French practices. Even more striking is the emergence, at the global level, of 5 or 6 cross-sectoral heavyweights (in energy, transport, and healthcare) that could, according to a GAFAM-type model[6] , account for over 40% of the high-risk industry by 2050. This would considerably weaken the role of national or regional authorities in risk governance.

Challenge 4: Differences in organizational and generational culture will test safety culture

Key Point

An ageing workforce, the cohabitation of several generations of workers, fragmentation, outsourcing, etc.:

- weakens safety culture in high-risk organizations;
- leads to changes in industrial and economic models: delocalization, globalization of the value chain, the rise of the shareholder model, cross-sectoral heavyweights increase their power;
- increases the cultural gap and undermines the Western safety management model.

6. Google, Apple, Facebook (Meta), Amazon and Microsoft.

5

More, and more diverse safety stakeholders

While the first signs were seen decades ago, organizational fragmentation is increasing. High-risk industries are becoming increasingly dependent on new activities and associated organizations that are external to their industrial sector. In this respect, the spread of digital technologies is blurring industrial boundaries. The multiplication and diversification of actors raises the question of how to improve coordination between the various organizations that contribute to the operation of high-risk systems. New entrants include software developers, telecoms service providers, and data suppliers. At the same time, we must not forget that safety is not always top priority among the various organizations that are involved in the operations run by high-risk industries (Bieder, forthcoming).

In terms of non-industrial stakeholders, change is ongoing. Beyond at-risk industries, the current safety governance model involves regulators and supervisory authorities who are supposed to be independent, and who represent the voice of the general public (Bieder & Villena López, 2022). However, while the role of civil society in risk governance is underlined in official documents, civil society, as such, remains absent from the model. At the same time, increasing societal expectations in terms of health, the environment and ethics, combined with a fall in confidence in experts and institutions, are limiting the public's tolerance of high-risk, polluting industries. The recent fire at the Lubrizol chemical plant in northern France (Rouen, September 26, 2019) demonstrates yet again that accidents, incidents and the consequences of pollution extend far beyond the social and political spheres (FonCSI, 2023). And even in the absence of death or widescale damage, an event can have catastrophic, long-term health and societal repercussions. Faced with the increasing desire to involve citizens in the governance of industrial risks and pollution—because they are affected by the issues—are we moving rapidly towards a model of safety governance where more decisions are taken by civil society and politicians? What could be the consequences of this?

Key Point

Challenge 5: More, and more diverse safety stakeholders

New industrial stakeholders will become part of the ecosystem of at-risk organizations:

- the boundaries between organizations will blur;
- at-risk organizations will be increasingly dependent on external entities (working in other sectors);
- safety will not necessarily be a priority for new entrants.

Civil society will expect more in terms of the environment and its participation in decision-making concerning high-risk industrial activities:

- the social consequences of incidents and accidents will be greater;
- the need to take full account of the voices of people living near at-risk sites and, more broadly, citizens, will have an impact on governance modes in at-risk organizations.

6

The governance model, based on the regulation-control-certification triad, will be revisited

Currently, governance encompasses the following three areas: regulation, certification, and control. Regulatory bodies and independent supervisory authorities are the pillars in this model. However, current megatrends such as technological acceleration, skills shortages and migration, the displacement of major centers of industrial power, a societal shift in risk acceptance, trust/mistrust in decision-makers, and the empowerment of other actors are already shaking up and blurring this arrangement, and could lead to a review of the entire regulatory and supervisory model as it exists today.

Currently, requirements are drawn up by regulatory bodies that are, in turn, backed by major Western industrial players and imposed on an industry as a whole, across different organizations, and even on a global scale for internationally-regulated sectors such as aviation. Will the Ukrainian conflict and developments in China exacerbate fragmentation into large geopolitical blocs, weakening inter-bloc cooperation, and strengthening intra-bloc cooperation? Or, on the contrary, will earlier trends reflecting a shift of major corporations from Europe and North America to Asia, and the growing influence of non-Western regulators, continue in the future? If the latter hypothesis proves to be true, it could destabilize current safety governance regimes (Bieder & Villena López, 2022). Would this lead to the development of new standards? Would high-risk companies move their headquarters to countries with less stringent safety regulations?

FIGURE 7: How is the 'classic' safety governance model evolving?

At national level, a redistribution of roles, responsibilities and power between the historical custodians of safety governance—regulators, supervisory authorities and industrial operators—is taking shape, based on the ability (or not) of these players to access the skills required by new megatrends. Regulators and supervisory authorities are increasingly seeing a shortage of highly-qualified personnel, not least because they are migrating to the more attractive private sector. In addition, safety authorities adopt and publish certain norms and standards developed by the private sector (which is not neutral), because they do not always have the resources to pay development costs or keep pace with (in particular, technological) trends. If economic actors become more powerful relative to the state and regulatory authorities, it is possible that, in some cases, we could see regulatory authorities being held hostage (called the "capture" of regulatory authorities by some authors), which would raise important questions about their independence in the domain of safety governance (Baram & Bieder, 2022). We can see another, dual imbalance between industrial actors and regulatory authorities, to

the detriment of the latter, in terms of access to (strategic) data concerning the detailed operation of systems, and the skills and competencies required to process this data. This situation could lead to safety authorities having to negotiate access with the industry. This could, in turn, trigger conflicts between designers, operators and authorities (Bieder & Villena López, 2022; FonCSI, 2021).

The certification of AI systems is clearly one of the key challenges that emerge from technological developments, and this situation raises questions about the role of regulatory and supervisory authorities, and their relationship with industrial operators. As the situation stands today, we are unable to analyze how deep learning systems work, in a way that would support a demonstration of their safety using standard methods. This major challenge drives most current efforts, and while aviation has initiated a program to set standards for AI, the situation remains difficult in other sectors (EASA, 2020; ANITI, 2022)..

Challenge 6: The governance model, based on the regulation-control-certification triad, will be revisited

Key Point

A lack of competencies among supervisory and regulatory authorities means:

- the control and development of safety standards migrate to the private sector;
- regulatory authorities may be held hostage;
- poor access to safety data and a lack of skills required to process it: this challenge may lead to negotiations or even conflict between designers, operators and authorities.

AI is a black box:

- AI certification is a major challenge, and raises questions about safety.

7

A shake-up of the current dominant approach to safety, based on anticipation and prescription

How is safety currently 'produced' in the high-risk industry? There are two main modes. First, we talk about 'safety as demonstrated': this macro model underpins how third parties (society, regulators) expect industries to ensure the safety of their operations. This model is based primarily on anticipation, compliance and external checks. High-risk industries operate within a very strict external framework in which regulatory bodies produce legislation, and safety authorities are responsible for certification and monitoring. At-risk industries are also highly internally proceduralized; practices are governed by technical procedures and organizational processes. While the 1990s saw the beginning of a trend towards an approach based less on compliance and more on safety performance, which allowed for contextual variability, more room for maneuver, and gave industrial organizations a stronger voice in defining standards, in practice this macro model remains largely based on anticipation, standardization and the clear allocation of responsibilities, in an approach that seeks to reduce uncertainty to ensure that risks are (fully) controlled. However, this visible, 'safety as demonstrated' model coexists with a number of real-life practices, at both operational and governance levels that are not entirely consistent with it. This second aspect of safety production is referred to as 'safety as practiced'. It comprises a set of safety strategies that are developed to adapt to an unstable, uncertain and complex reality. It cannot be captured by audits and, in terms of management and governance, does not reflect formal distinctions between actors and organizations (Bieder & Villena López, 2022).

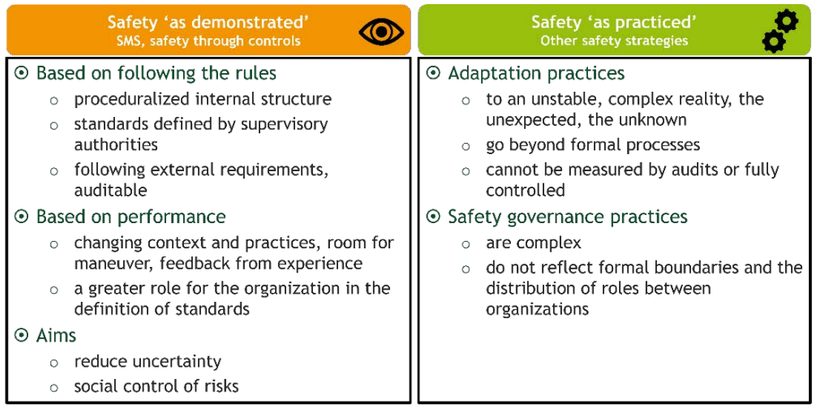

FIGURE 8: Safety 'as demonstrated' and safety 'as practiced'.

The megatrends that are likely to emerge in 2030–40 could impact the balance between these two safety models. And views diverge as to which way the scales will tip. Will the two types of safety production reinforce each other, or might we even be on the cusp of a new paradigm? Arguments exist in favor of both sides, but we must be cautious when trying to imagine possible futures.

Challenge 7: A shake-up of the current dominant approach to safety, based on anticipation and prescription

Key Point

As things stand today, the management and demonstration of safety in at-risk organizations is mainly based on anticipation, the reduction of uncertainty, compliance with rules and external checks, i.e., safety 'as demonstrated'.

Current megatrends could:

- shift the cursor towards an approach that takes greater account of the less-visible, less-accountable production of safety, based on real-life operations and governance, i.e., safety 'as practiced';
- lead to the emergence of a new paradigm for managing and governing safety in at-risk organizations.

Part Two

3 approaches to industrial safety between now and 2030–40

1

Adopt a more open approach to safety

As noted above, the growing anticipation capabilities of systems in known domains of operation means that the overall level of safety should continue to improve. At the same time, however, the growing complexity that accompanies technological acceleration and other megatrends may make the system more fragile. We may see the emergence of new 'normal' accidents that are not linked to anomalies, but to the unpredictability of 'normal' system behavior. Even if the overall level of safety improves, the residual risk of unpredictable and catastrophic accidents, which illustrates the limits of the control presented in the official safety discourse, may not be accepted by society, where expectations are also evolving (Pariès, 2022).

If the observed megatrends are confirmed, we can expect to see a change in how we view safety in at-risk industrial organizations. Future thinking about safety will require a more open, 'vertical' approach, and a move away from isolated, level-by-level responses.

The approach also needs to be more 'transversal', achieved by broadening the unit of analysis or how safety is viewed. Safety must be considered in the same way, and in combination with, other strategic challenges. We must not only move away from the idea of safety in isolation, and connect it to the company's other priorities, but also adopt a more global approach, which situates the at-risk industry in the context of a rapidly changing world.

Adopting this broader, more integrative approach has consequences not only for the safety management model and method, but also in terms of how it is applied organizationally. These consequences are briefly described below.

Key Point

Approach 1: Adopt a more open approach to safety

- vertically:
  - promote an overall vision of the organization's safety, which goes beyond its level-by-level approach;
- transversely:
  - consider safety in combination with the organization's other strategic challenges;
  - consider the at-risk organization in the changing, global context.

2

Move beyond current safety management and governance strategies

New systemic vulnerabilities are concomitant with the complexification associated with technological acceleration. In addition, global growth, climate change, the multiplication of interfaces between the various actors in society (companies, regulators, public authorities, NGOs, the media, citizens, etc.), the hybridization of technologies, rampant interconnection and networking are other sources of complexity and uncertainty. A striking illustration is the blurring of the boundaries between risks, roles and responsibilities, which is making silo-based safety management and governance irrelevant. For example, massive digitization is increasing exposure to cyberthreats, which can degrade safety in high-risk organizations. However, there is a historical distinction between industrial safety and security, not only with respect to governance, management, and methods, but also research (Bieder & Villena López, 2022). Another example that calls for a more integrative approach concerns technological and natural risks. Global warming is increasing the intensity and frequency of extreme climatic events, and the future is likely to see the advent of more NaTech accidents[7] such as the Fukushima disaster in Japan in 2011. Managing safety differently is likely to involve taking a holistic approach, both at the level of management and governance. A move away from silo-based regulation would be a clear break with the current approach to governance. This would, in turn, change structures and control mechanisms and maybe even governance actors (Matyjasik & Guenoun, 2019).

The current safety model is essentially based on the reliability of system components and various governance jurisdictions depending on the risk family. However, it is clear that it is less and less able to address observed trends. By its very nature, it is ill-equipped to cope with the unpredictability of complexity. Future thinking about safety requires a focused effort to develop a more global model, in which strategies are geared towards the reliability of systems as a whole, rather than component-by-component. On the other hand, until now, safety demonstrations have mainly focused on externally-visible and justifiable aspects of the decisions and actions that companies take to ensure safety. However, we know that safety is also produced in less prescriptive ways, through real-life practice, and that, when faced with growing uncertainty and instability, the contribution of 'safety as practiced' becomes more important. This means that, in the future, this less-visible, less-demonstrable aspect of external safety production will be more fully, both conceptually and in practice, integrated into the organization. However, going beyond current safety strategies does not mean abandoning them! The current model has proven its worth, and has made it possible to achieve the very high levels of safety currently enjoyed by at-risk industries. However, to meet the challenges of the future, safety strategy needs to be part of a 'stronger' theory-based approach, which explicitly takes into account the effects of complexity.

Key Point

Approach 2: Move beyond current safety management and governance strategies

- ▷ develop integrative rather than jurisdictional approaches to risk and safety:
  - consider safety AND security;
  - consider natural AND technological risk.
- ▷ strengthen risk management models based on anticipation, and extend them by focusing on theories and methodologies that take better-account of complexity and uncertainty.

7. A NaTech accident is a technological accident caused by a natural event.

3

Ensure consistency between prescription, hierarchy and autonomy at the organizational level

> *We think about the workstation level when it is already the design and processes that are the issue, about the process level when it is already the company's strategy that is the issue, and about the strategic decision-making level of a company when it is the global value production chain that is generating instabilities... And while safety studies are carried out for internal and local changes within the company, this is not the case for major changes affecting the world.*
>
> (Pariès, 2022).

In high-risk organizations, safety is generally managed in successive layers; the starting point is technical equipment, followed by the operator and his or her workstation, teams and occupational groups, procedures, processes, the department, production facilities, etc. But safety strategies can lag behind increasing complexity, and may become irrelevant in the face of accelerating change and new challenges (Pariès, 2022).

Technological acceleration is also leading to a debate on innovation and safety regulation, and here the agenda of regulatory and supervisory authorities is barely able to keep up with the pace with innovation. Two main arguments stand out. The first is based on the imperative need to benchmark new technologies—despite the fact that safety levels are currently impossible to demonstrate—develop standards, and define a regulatory framework. The second is the need to innovate, and rapidly adopt new technologies to avoid falling behind other, more adventurous countries, and losing market share. This implies not thinking too much about constraints such as safety demonstrations, and technical, societal or ethical obstacles. From this point of view, waiting for the publication of *ad hoc* regulations is a strong brake, and would be tantamount to missing the 'competition train'. 'Innovation leads, regulation follows' (Deloitte, 2016): it could be said that we're betting on the fact that those who take the plunge will not only win economically, but also achieve a better level of safety. This implies being proactive, and developing isolated innovation 'bubbles' that enable new products to be tested, free from regulatory delays (FonCSI, 2021).

Finally, while the systemic dimensions of safety go beyond the classic sphere of interactions between industrialists, safety authorities and regulators, there are few places where safety is discussed. As indicated in the Foreword, the megatrends that are affecting the industry and the workplace are at the heart of the industrial world's preoccupations; although the theme is addressed by numerous think tanks, and has been the subject of studies in a variety of fields, few adopt the angle of safety. While the future of the industry is widely debated at the highest national and global levels, safety remains more-or-less on the sidelines. It is still—and too often—seen as a constraint, or an obstacle to achieving better corporate performance in other domains. In general, industrial safety is only considered internally, even when the company's boundaries have been broken down. The challenge, therefore, is to break out of safety-focused arenas, address it in the same way as other strategic challenges, ensure that it is discussed in the influential and decision-making circles that it has not, so far, managed to penetrate in any depth, and create new discussion forums, or reinforce the few that currently exist (Pariès, 2022).

Approach 3: Ensure consistency between prescription, hierarchy and autonomy at the organizational level

Key Point

- in the face of acceleration, move beyond hierarchical boundaries and chronological approaches within the organization, and think about safety by integrating 'what happens next';
- to reconcile innovation, regulation and safety, create temporary physical and regulatory innovation 'bubbles';
- move away from the view 'safety = constraint', and also look at it as an opportunity;
- as is the case for other economic and political strategy questions, ensure that safety issues are discussed at the highest decision-making levels.

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