



Ideas for the future of safety science

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This article is a contribution to the special issue on the future of safety science. It discusses the three areas indicated in the call by the editors: history and evolution of safety science; new models, processes and theories in safety science and emerging risks in safety science. In the first section on the history and evolution of the field, *(Re)writing history*, I argue that an interesting task is to challenge what has become a taken for granted view of the past. I illustrate this claim by revisiting and challenging the popular view of safety which describes three ages in the evolution of safety science (technical, human and organisational). I then reinforce this by arguing about the presence of relatively independent research traditions which structure our understanding of safety. In the third section on new models, processes and theories, *Convergence versus Divergence*, I discuss the problem of research traditions developing independently, and I advocate a strategy of convergence to complement this process of divergence, while shortly discussing the practice-theory gap. Finally, in the third section on emerging risks, *How is safety globalised?*, I argue that one challenge for safety research is to keep up with change, some of which are perhaps of an unprecedented scale.

Introduction

This article of the special issue on the future of safety science follows editors' guideline to consider three potential themes for discussion: history and evolution of safety science (theme 1); new models, processes and theories in safety science (theme 2) and emerging risks in safety science (theme 3). But, instead of selecting one theme among the three, it combines them into a single piece. On the one hand, a reflection on new models, processes and theories of safety science (theme 2) must imply a certain idea of past models, hence something about the history and evolution of the field (theme 1). On the other hand, tackling emerging risks in safety science (theme 3) should be the ambition of new models, processes and theories (theme 2) so the two should be also strongly linked. Therefore, it seems highly relevant to approach the special issue through an articulation of the three themes rather than considering only one of them.

This choice of combining the three themes this way is motivated first by the idea that, in a scientific field, history matters. It matters first because to understand models and theories, a good grasp of their history is a guarantee of a better understanding of their generis and limits when it comes to practice and/or theory. Second, it matters because one difficulty in safety research is to keep up with history as it unfolds, to keep up with its implications on practices, models and theories. As we go back in time, this point is obvious. The way we think and experience safety in the 21st century is not the same as it was in the early 20th century.

But it is misleading to think that such a historical sensitivity applies only to situations of the distant past. Safety was not the same at the end of the 20th century either, 30 to 40 years ago, than today, in the 2020s. Thus, many today's safety problems find their roots in the current and evolving nature of our increasingly global interconnected world. Second, this choice is motivated by a personal long-time interest in keeping a big picture in sight when it comes to safety, and in reflecting and elaborating on the conditions under which this is a reasonable and feasible prospect, empirically, theoretically and practically. This problem is even more pressing when considering the world interconnections just mentioned.

An important source of inspiration and inputs for this article is the publication of a book which followed a workshop in 2017 in Paris grouping researchers from different traditions, to explore contemporary topics in the field of safety from a multifaceted perspective. Each participant wrote a chapter, and these chapters were then commented by some authors who produced important contribution in safety research over the past 4 decades (see in Le Coze, 2019). This special issue of the journal on the future of safety science is also therefore an opportunity to pursue this collective initiative. The wealth of ideas, debates, discussions and exchanges created through this workshop then writing process and outcome serves as a primary material in this article for many references but also quotes extracted from the chapters of this collective book.

One of the core argument which structures this article derives directly from the design of this workshop then the publication of the following book. It is the importance of thinking safety science through research traditions. To think through research traditions is to analyse how safety as an object is conceptualised, methodologically studied, advocated by networks of actors but also how these traditions shape (or are shaped), diffuse or translate outside of academia into practices through complex interactions of a diversity of actors (e.g. academics, safety professionals, consultants, regulators, publishers, see Le Coze, 2019c). Another strong contention is that the relations between research traditions should be problematised and traditions sh/could be articulated (although how is a key question) in order to grasp the multifaceted aspect of safety as a research object, both for academic and practical purposes.

Building in turn on the three themes suggested by the editors of this special issue, the article explores this challenge of dealing with research traditions as a fundamental one in the field. The first theme suggested by the editors is history and evolution of safety science. This is the first section of the article, untitled *(Re)writing history*. It comes back on a popular view of the evolution of safety which claims that it moved in three stages: technical, human then organisational. This section is critical about this view and refines this discourse with the help of an introduction to research traditions. Research traditions constitute a prism through which themes 2 and 3 of the special issue are then discussed. The second section, *Divergence and*

Convergence elaborates on new models, processes and theories by addressing the problem of valuing the strengths of traditions while questioning the drawback of considering them in isolation. Third, *How is safety globalised?* on emerging risks in safety science discusses how to move on with a program which would embrace the new situation of increasingly interconnected world and associated range of new risks, and their possible evolutions.

1. (Re)writing history

Writing a history of safety science is an important task. There are many good reasons to do so (Le Coze, 2015a) and one can easily find a similar approach in other fields (e.g. sociology, management, etc.). But writing about history is very often also about revisiting or rewriting popular views of the past. For instance, interpreting, analysing and writing about an event such as the French revolution differs according to the epochs of the historians who worked on this topic (Dosse, 2010). There are, in history, according to different epochs, renewed areas of investigation, but also alternative ways of writing about the past which are not value-free but politically situated instead. There is in another word, a history of history.

1.1. Historical rebuttal of reflexive modernity

Let's illustrate this assertion with a recent example, the analysis by Fressoz of Beck's "*risk society*" (Fressoz, 2012). For Fressoz, Beck has simplified the past and, as a consequence of this, has also simplified his sociological description of the society of the 1970s onwards. Beck's thesis is well known (Beck, 1992). The risk society is one of reflexivity, or second modernity, for which science and technology (S&T) is no more accepted or unchallenged forces of progress. They are questioned by civil societies which are more aware of S&T potential negative consequences (and the nuclear industry is one key example). Beck opposes this late modernity to a previous modernity, far more tolerant and happier with the association of progress and S&T.

Fressoz, as an environment historian shows instead first that in the past, and despite what Beck seems to imply, industrialisation was opposed to by civil society. Awareness of the safety, health and environmental consequences of burgeoning plants, factories and manufactures existed for a long time before the end of the 20th century, right at the heart of the industrial revolution of the 19th century. Fressoz adds a second point. Despite these existing oppositions back then, technologies were developed anyway, an observation which is still for him highly relevant today (e.g. nuclear industry, see also Pessis, Topçu, Bonneuil, 2013) which invalidates the thesis of a second modernity by Beck.

For Fressoz, through his historical data and study, Beck's thesis of a reflexive modernity is therefore incorrect. First, it refers to a past which is simplified, or worse, a past that did not even

exist. As a sociologist, Beck is a poor historian. Second, Beck's normative ideal of a risk society does not even describe our current situation. As a sociologist, Beck is this time a poor analyst, or more of an utopian than a scientist. If we analyse Fressoz's analysis, his interest for the topic derives at least partly from the contemporary existing theory of Beck, and his conclusion is one with a political argument about the lack of reflexivity in today's societies, against Beck's normative claim. One does not need to agree entirely with Fressoz and his rejection of Beck (**the risk society remains a popular and valuable framework**) to see the value of proceeding as he does. In this case, history is a way of making a statement about the present.

1.2. Historical rebuttal of popular view of safety science evolution

Let's apply this to the field in relation to the first theme of the special issue, history and evolution of safety science. One popular view of the evolution of safety research is to describe it as a pattern of interest which started with engineering, followed by human factors then organisational factors. Hale, Baram and Hovden have been advocates of this narrative (Hale et al, 1998) which is characterised by a 'first age' during which "*safety was seen as a technical problem*" (Hale et al, 1998, 2), a 'second age' for which "*the human factor was added and came gradually to dominate thinking and writing through the 1960s and 1970s*", (Hale et al, 1998, 2).

There was then a 'third age' "*which now focuses directly on the structure and functioning of management*" (Hale et al, 1998, 3). It has become a popular view in the field, one which seems to be taken for granted and widely admitted (see also Hollnagel, 2004). However, twenty years after, is this proposition still a valid picture of the past? There are many reasons to doubt about it. From our current vantage point, things appear far more blurred than a neat succession of three ages.

First, looking back, it is obvious that many research traditions were and have been involved in parallel, and not in turn (more about this below). Let's take just one example. The sociologist Turner published his analysis of disasters in 1978 (Turner, 1978) before the first psychological book on human error (Reason, Mycielska, 1982). Reason was later inspired by Turner (Reason, 1990), but Reason did not become a sociologist and remained a psychologist. A psychologist who expanded his individual level of analysis to a system one, but one who remained with psychological analytical tools (Reason, 2008, 2013).

Second, these three ages seem to exclude studies of state, law and regulation whereas it is an important research tradition with books again, in the 1970s (Stone, 1975) and the 1980s (Braithwaite, 1985). Traditions do not seem to communicate much and can remain invisible to each other. For a psychologist, the problem of safety is not the same as for a sociologist because

they construct their objects differently, and their range of references, readings, experiences and discussions revolve around this construction.

For a political scientist or legal scholar, it is also different. This is precisely what is witnessed in the diversity of research traditions. They derive from established backgrounds or disciplines which framed the way researchers approached their objects as explained above. These parallel lines of investigations are maintained for this reason, and none of these traditions replace each other. Swuste and colleagues' historical work show this quite well (e.g. Swuste et al, 2010, Swuste et al, 2012).

That's the second point. Research traditions do not replace each other because they live their lives independently, or partly independently. They do only partly because they borrow notions from each other which travel across traditions. Examples are notions such as resilience or reliability. This is not without creating confusions. A previous special issue of this **Journal** already mentioned earlier in this paper was precisely about the difference between resilience engineering and high-reliability organisation. These traditions use different words for similar phenomena (Wears, Roberts, 2019).

But one could also argue that Hale et al had perhaps a mix of research and practice in mind when they described this evolution of safety science. But, as already noticed by Hopkins (2006), this is not what practitioners (or consultants) describe. They refer to the same topics (technical, human, organisational) but propose an alternative historical order. They start with technology, followed by organisation then human factors. Hopkins identifies this gap without proposing an explanation, "*we do not need to resolve this contradiction here*" (Hopkins, 2006, 587).

Yet, one interpretation of this discrepancy is that on the one hand, researchers think more in terms of disciplinary contributions to safety science. They consider engineering, then psychology/ergonomics and finally management/sociology from their own experience of the production of knowledge in the field (whether we agree or not with them). On the other hand, practitioners think in practical terms and do not refer to disciplines. They think in terms of what they concretely do, based on their experience in the industry.

They see instead a historical pattern of technical solutions first, followed by safety management systems fixes (as in the normative approach promoted by standards) then by behavioural based safety solution (or sometimes, safety culture). Of course, it is quite possible that when we mean practitioners, it would be more exact to talk about consultants. An analysis of the genesis of graphs typically supporting this discourse (figure 2) would likely lead back to consultants promoting behavioural based safety, creating the three stages of safety evolution as a marketing

and performative tool for their business (Hopkins' connect this graph to a consultancy firm *Step Change Group*, Hopkins, 2006).

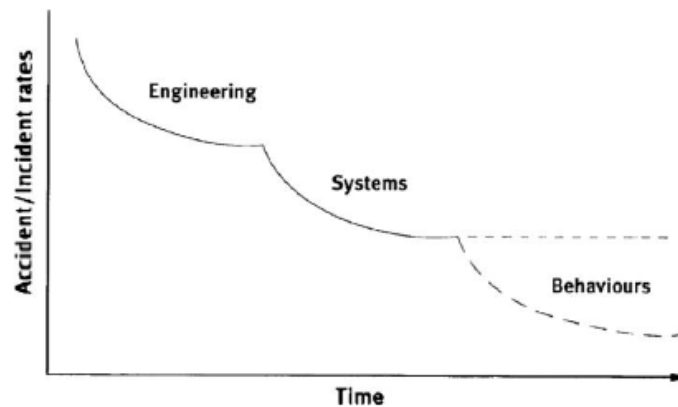


Figure 2. Practice view of safety evolution

But, in his seminal history of American business, Chandler considers that the development of the railway industry in the 19th century as the first modern organisation (Chandler, 1975) is a product of accident. *“Even before the road had reached the Hudson River, the Western suffered a series of serious accidents, culminating in a head-on collision of passenger trains on October 5, 1841, killing a conductor and a passenger and injuring others. The resulting outcry helped bring into being the first modern, carefully defined, organizational structure used by an American business enterprise.”* (Chandler, 1975, 97).

So from this single piece of historical evidence, practitioners' discourse can also be invalidated. Organisational issues have long been at the heart of safety practices, and so regulations too (more thorough evidence is found in **the works** of **historians** on the relationship between industry, industrial development, pollutions and accidents, e.g. **Le Roux**, 2014). In fact, and in general, it would be very difficult to distinguish neatly between these different steps of safety evolution because there has perhaps never been any of these steps. As a consequence, this broad, popular view of the past (whether from an academic or practice point of view) establishing several ages in the evolution of safety, is at best a crude one because there has always been a complex mix of technical, human and organisational measures associated with safety.

This popular view reflects the views of their advocates, and their own angle of analysis, or interests. One idea for the future of safety science is therefore to keep writing about the past to help clarify the complex interactions between these different research traditions and practices, and against a simplistic reading of its history. Recent examples of (sometimes critical) analyses of the way popular authors such as Heinrich, Reason or Perrow have been interpreted and

portrayed by authors from different traditions are now available (Le Coze, 2015b, Busch, 2019, Larouzée, Le Coze, 2020). These authors are careful about authors' texts, ideas and developments, and are not satisfied with a lack of contextual knowledge which would simplify their contributions retrospectively.

1.3. Research traditions in safety

Another option is therefore to be careful not to conflate the diversity of ways of framing safety by a range of authors who developed their own lenses, sometimes in such an influential manner that they created schools with enduring influence. Perrow, Reason, Weick or Rasmussen, among others in the 1980s, come to mind. A closer and nuanced look at safety research reveals indeed the presence of research traditions which have shaped our current view of safety. In this respect, I propose to situate the stabilisation of these traditions, with a bit of simplification which does not alter the argument of this article, in the 1980s and 1990s and contend that one strong influencing aspect of these research traditions is the scientific disciplines in their background (cognitive psychology, sociology of organisations, organisational psychology, political science, ergonomics, etc, Le Coze, 2016, 2019b).

If one exclude “hard science” oriented traditions stemming from mathematics or engineering in this article, I suggest that it is relevant to distinguish seven of them and their associated authors: first, incubation, safety culture and learning, second, high reliability organisations, third, normal accident and the critical perspective, fourth, safety regulation and socio-legal perspective, fifth, a socio-constructivist perspective, sixth, safety climate, leadership and management, then finally, human error, interface design and system safety. I introduce these traditions and how they innovated in their time and created strong lenses through which one can experience and think of safety, which explains the reason why they have been shaping the background ever since (table 1).

Table 1. Research traditions (1980s, 1990s) and their emphasis

Research tradition (1980s/1990s)	Emphasis	Main authors
Incubation, Safety Culture & Learning	Understanding disasters (and safety) through a cultural view of organisations, with information and signals as core concepts	Barry, Turner, Nick Pidgeon, David Blockley
Normal accident & the Critical Perspective	Analysing disasters through a critical angle of the relationship between business and society, with power as a central	Charles Perrow, Lee Clarke, Paul Shrivastava, Scott Sagan

	analytical tool	
High-Reliability Organisations	Studying ethnographically complex organisations in daily operations to infer properties of reliability in very trying and unforgiving conditions	Karlene Roberts, Paul Schulman, Karl Weick, Todd La Porte, Gene Rochlin
Safety regulations and socio-legal perspective	Grasping disasters and safety from a legal and state-oriented understanding of societies in relation to compliance issues	John Braithwaite, Andrew Hopkins, Joseph Rees
Socio-constructivist perspectives	Introducing the value laden, uncertain and relativistic dimensions of science and technology in the analysis of disasters and safety	Brian Wynne, Trevor Pinch, Ron Westrum, Diane Vaughan,
Safety climate, Leadership & Management	Describing safety through work situations at the level of team interactions and climate , through leadership, voice and speaking up or safety management	Dave Zohar, Ian Glendon, Rhona Flin, Andrew Hale, Patrick Hudson, Amy Edmondson
Human error, interface design & system safety	Conceptualising events and engineering safety with the help of cognitive models combined with complexity discourse	James Reason, Jens Rasmussen, Erik Hollnagel, David Woods

1.3.1. Incubation, safety culture and learning

Barry Turner published a landmark study in 1978 in which developed the incubation model of disaster. Subsequently, during the 1980s and 1990s, he worked in close collaboration with the researchers David Blockley and Nick Pidgeon in the UK and in a multidisciplinary context (i.e. engineering, psychology, sociology). The incubation model has developed strong links to early conceptualisations of the notion of safety culture and learning.

The innovation of this model back in the late 1970s and during the 1980s was to extract a common pattern across a diversity of disasters' reports, and to show how individuals could be likely to miss signals because of the complex social processes exhibited by bureaucracies, including prominently their cultural dimensions. Disasters appeared to be not the products of the mistake of a single individual, but the products of individuals interacting and interpreting their world in organisationally and socially shaped contexts instead.

This tradition was one of the first to connect with the safety culture debate in the late 1980s when the concept was first introduced. By providing early inputs to the topic and advocating a careful take on this ambiguous notion, Turner and Pidgeon explored the implications of the

empirical and theoretical dimension of the incubation model. Another important concept which seemed to derive quite naturally from the incubation model was learning, which also became in the following years an additional core idea in the safety field.

1.3.2. High-Reliability Organisations

Another tradition is the body of work around High Reliability Organisations in the US during the 1980s with authors such as Karlene Roberts, Todd La Porte, Paul Schulman, Gene Rochlin, but also Karl Weick. The difference with the previous tradition is the focus on daily operations instead of a focus on past events, but the interdisciplinary nature of the research is also a common point (e.g. organisational psychology, political science, social psychology, management).

What high reliability researchers delivered were the first ethnographic descriptions and conceptualisations of the daily operations of these specific organisations for which the social and technological environment was unforgiving. They looked for some of these social, organisational and managerial properties that could help explain their ability to succeed in these particularly unforgiving contexts, within this requirement of operating in nearly-error free systems.

Several features appeared to be connected to the ability of maintaining reliable operations including redundancy within, among and between teams, namely the possibility for tasks to be performed while being checked by several individuals. The description of a property such as having the bubble was another of these features which meant that some individuals in managerial positions had a broad view of operations which allowed them to keep the big picture in mind. The concept of collective mindfulness further theorised during the 1990s some of these properties into what became a successful practical and theoretical proposition.

1.3.3. Normal Accident and the critical perspective

In the US context, this posture was in dialogue with the approach, style and intellectual posture followed and conveyed by Normal Accident in the US by Charles Perrow published in 1984. As introduced above, as a very influential book, it was debated and advocated in different ways by authors such as Paul Shrivastava, Lee Clarke or Scott Sagan during the 1990s. The value and innovation of Perrow's book was first its synthetic angle, second, its provocative thesis and third, its collection of cases.

The synthetic angle was the ability to identify, associate, classify and then visualise a new category of organisations: high-risk systems. The provocative thesis declared some accidents to be inevitable in certain kinds of systems, and implied that nuclear powerplants had to be abandoned for this very reason. The collection of cases or stories of accidents provided an

overview of the diversity of ways accidents could happen in various hazardous processes, based on a critical stance.

The initial tensions which existed between the message of Perrow based on retrospective cases and what the high-reliability organisation researchers looked into through fieldwork of daily operations during the course of the 1980s was pictured as two opposite perspectives to choose from by Sagan who, following Perrow, finally believed that accidents were inevitable. The debate never really settled and extended versions of the normal accident thesis were developed, as for instance by Snook at the end of the 1990s.

1.3.4. Safety regulations and the socio-legal perspective

In different countries in the 1980s and 1990s, safety regulations and socio-legal views also delineated the contours of a research tradition among sociologists, political scientists and legal scholars such as Christopher Hoods, Aaron Wildavsky, John Braithwaite, Andrew Hopkins or Joseph Rees, who studied how laws, public policies, regulations and inspections frame the conditions of safe performances. Andrew Hopkins, over the years, developed his own specific analytical lenses, combining descriptive and normative sociological interpretations beyond this socio-legal angle, into widely read accounts of disasters, from the end of the 1990s onwards [\(more about this author in section 2\)](#).

This tradition explored and showed how the state, through laws and inspections, played a key role in designing the conditions surrounding the practices in safety critical organisations. The multiplicity of options and their evolutions over time when it comes to shaping companies' expectations through legal requirements, but also through principles and implementation of control of these requirements by inspectorates of agencies, translate societies' degree of concern for safety through their ideological and political orientations (e.g. command and control, self-regulation).

The notion of regulation regimes developed at the end of the 1990s aggregated various of these dimensions into a broad concept. Interpreting accident and safety as a result of how well designed, implemented and controlled legal expectations are, such regulation regimes must be developed to achieve the right combination of resources and skills but also the right balance of persuasion and sanction. In this ambition, regulation regimes face the risk of regulatory capture of private interests which might attempt to limit the degree of control and oversight to which they are exposed.

1.3.5. Socio-constructivist perspectives

It makes sense to distinguish what could be called a socio-constructivist orientation of accidents and safety with authors in the US and the UK such as Ron Westrum, Robert Gephart, Trevor

Pinch, Brian Wynne and Diane Vaughan because of their connections with an important new wave of social studies approaching science and technology from very innovative angles. These angles consisted in challenging the much taken for granted idea that science and technology come out of rational minds disconnected from the historical and social contexts within which they exert their sociocognitive skills.

In this view of science and technology, uncertainties, controversies and values have a stronger part than in the previous interpretation of science and technology. In this view, social and technical realities are tightly intertwined. Applied to disasters and safety, such a view implies a careful analysis of the complexities associated with the design, interpretation and handling of hazardous artefacts.

Within this tradition, their uncertainties, ambiguities and messiness are part of the picture, and generate this potential for, sometimes, deceiving expectations and predictions. Understanding safety or accident based on these ideas leads to a nuanced perspective on practices of engineers and managers, on decision-making processes, on the possibility of avoiding surprises or not. Within this tradition, knowledge is not about the discovery of an outside world, but the construction of a temporary, limited, and unstable understanding of the world.

1.3.6. Safety climate, Leadership & Management

From a more psychological, and very often combined system perspective, areas such as safety climate, safety leadership, teamwork and safety management systems can constitute other examples of important themes in the safety field to be associated with a research tradition found in many countries with the work, for instance, of Rhona Flin, Eduardo Salas, Patrick Hudson, Amy Edmondson, Dov Zohar, Andrew Hale, and Ian Glendon.

Understanding the psychology of individuals in relation to different kinds of contexts, whether in teams or emergency situations, has made a difference in the way safety could be thought and promoted in organisations. Conceptualising safety climate through psychological and psychosociological insights allowed researchers and practitioners to identify key dimensions which favour interactions conducive to safe performances in the way people interact, speak up, and feel empowered to do so.

Describing principles of team leadership which promote safety and translating this knowledge into crew resource management programmes are some examples of important contributions which were developed in the 1980s and 1990s with the help of this tradition (and the next one). Some of these authors extended their perspective from individuals to systemic, safety management systems, directions, to include a broader view, with links to the safety culture concepts.

1.3.7. Human error, interface design & system safety

Closely connected to this psychological and psycho sociological tradition but with a stronger link to an engineering mindset and ecological perspectives of cognition is the tradition exploring human error, interface design and the system view of safety/accidents in the 1980s onwards. Cognitive (system) engineering, naturalistic decision-making but also system safety as promoted by authors such as Jens Rasmussen, James Reason, Donald Norman, David Woods, Erik Hollnagel, Gary Klein, and Nancy Leveson innovated in the field of safety in many ways.

This tradition made a difference with its conceptualisation of human error. Clarifying this important issue through cognitive models of how the brain (and body) operate in complex environments opened new preventive strategies and options. Instead of immediately blaming individuals, the tradition argued that it was best to look into contexts in relation to strengths and limitations of cognition. Expanded through systemic models of safety and accidents, and often served by appealing and heuristic visuals, this new understanding of how individuals perform in real life situations proved invaluable to practitioners.

The engineering or design rationale of this tradition indeed tremendously contributed to its practical relevance as in the field of interface design for which guidance was needed in order to incorporate models of cognition that would increase the expected reliability of the coupling between operators, displays and the world. But prevention practices in companies, such as learning from events, also greatly benefited from these developments by targeting measures beyond individuals, including design of technology or organisation.

1.4. Implications of research traditions

A presentation of these traditions might appear at first as creating unnecessary refinements between authors and ideas who contribute to an understanding of the same topic. This is especially true from the point of view of practitioners who do not have to enter in what seems to be only academic concerns. But as expressed by Pidgeon, and further developed in the following section *“such distinctions matter – whatever we might think about the desirability of achieving a requisite synthesis – since disciplines socialise their members into particular understandings of how the world works and how to study it.”* (Pidgeon, 2019, 272). An example of analysis between two traditions, high-reliability organisation and resilience engineering can be found in the articles of a special issue in this journal (Wears, Roberts, 2019). There are many implications associated with a clarified background in safety science through research traditions, one of which we now turn.

2. Convergence versus divergence

2.1. Research traditions as diverging frames

One issue in science in general is specialisation. Safety does not escape this issue. However, the virtue of specialising can also hinder our understanding of problems, phenomena or processes which are multidimensional or multifaceted. Such a statement has been written or heard countless times but the issue remains. Why ? Simply because safety as an object always strongly depends on a point of departure which consists of an established discipline or an existing body of knowledge bringing its own specific conceptual, methodological, analytical and empirical background to the field. The boundaries created by this process operate through a cognitive closure. It is clear when applied to historical analysis of safety as shown above.

A tradition cuts a slice of the world through its methodological and conceptual lenses which is reinforced by networks, funding, publications or academic careers. It is the same when it comes to the second topic of this special issue, new models, processes and theories. The view of safety science through research traditions as advocated in this article in relation to theory development is one of divergence, namely one based on a diversity of options to frame an object.

In this section, I develop the idea that such divergence of traditions should also be complemented by convergence, namely attempts, under certain conditions, to articulate traditions in order to better perceive the multifaceted nature of safety. Divergence is visible through the enduring existence of these traditions as separate or sometimes competing ones. As already hinted previously, this influence of traditions is not only theoretical, it is also social and institutional, reinforcing the network of researchers who built their professional identities in relation to these traditions. This reality is materialised quite well in recent collective books perpetuating these networks and the strength of these identities.

Smith, Hoffmann, (2017) is one example in the human error, interface design and system safety tradition; Hagen (2018) is another for the safety climate, leadership and management tradition; Ramanujam, Roberts (2018) in the high-reliability organisations one and Drahos (2017) for the safety regulations and socio-legal perspective. These are typical examples of books in which one can see how researchers collectively consolidate, strengthen or reinforce the traditions identified in this article.

Could it be different? If looked at carefully it seems natural to observe divergence considering the mix of philosophical, methodological and conceptual principles which underpin their unique rationales and make them distinct, as stressed by Pidgeon in the earlier quote. This issue is, of course, not restricted to this field, and any general introduction to domains as vast as economics, psychology, sociology or biology reveal the exact same situation.

Plurality of schools in these fields prevail over unified theories. This has to do with the incredible complexity of reality which proves susceptible to several concurrent descriptions, which defeats our cognitive restrictions, but which is also socially amplified by specialisations in science (as shown with the selection of recent collective books above). But if merging traditions in one unified theory is unlikely, does it rule out other research strategies? What about the idea of convergence rather than of merger? These questions are foundational issues for safety science (Le Coze et al, 2014).

2.2. Beyond divergence...convergence?

Convergence could be a milder form of merger. Merging seems to imply that existing traditions would disappear, subsumed or absorbed within a new broader one, which doesn't make sense. Converging would not be a superior form of practicing science, it would be a complementary one to diverging. If one uses another vocabulary, convergence could be described as a multidisciplinary or interdisciplinarity endeavour, instead of a disciplinary one. Multidisciplinarity on the one hand recognises disciplines - or traditions - and juxtaposes them. Disciplines (or traditions) are only presented side by side, and not articulated. Interdisciplinarity on the other hand means that a high level of coordination of the traditions is tempted (theoretically and/or empirically), without pretending to absorb them in one unified scheme that would threaten the legitimacy of their independent existence and status. They would in this case converge rather than merge or diverge (table 2).

Table 2. Divergence and Convergence in safety research

Divergence	Disciplinarity	Research traditions exist independently without comparison
Convergence	Multidisciplinarity	Research traditions are made visible, aware of each other, and, sometimes juxtaposed and compared
	Interdisciplinarity	Research traditions are aware of each other but also combined, coordinated or articulated (empirically and/or theoretically) according to their compatibilities into

		wider schemes
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In safety, Rasmussen discussed this (Rasmussen, 1997) and I suggested to define his ambition as *“a strong program for a hard problem”* (Le Coze, 2015a). This converging prospect is widely shared in the community of researchers who have been involved in this field for several decades as expressed by many influential safety writers in the book which came out of the initiative described in the introduction (Le Coze, 2019). For instance, Hollnagel writes that *“the main issue with safety – and the reason why it is an ever-growing problem – is that the lack of safety neither is due to a single factor nor can be comprehended by a single view. Safety is not a unitary problem and there are no unitary solutions. A contemporary approach to safety should recognise that and therefore to try to embrace multiple perspectives in a comprehensible way.”* (Hollnagel, 2019, 266).

He opposes strategies of *depth-before-breadth* versus *breadth-before-depth* which is another way of describing convergence versus divergence (or disciplinary versus multidisciplinary/interdisciplinary work). *“A strategy of depth-before-breadth makes it possible to pursue a single idea until the objective has been achieved, while at the same time limiting the mental effort required. A strategy of breadth-before-depth means that several foci must be considered at the same time and is therefore generally less appealing.”* (Hollnagel, 2019, 266).

The same tension and difficulty are expressed by Flin in the book. *“While it is perennially pointed out that we require multidimensional approaches to studying safety, the reality is that we have a multidisciplinary subject, composed of various breeds of social scientist specialising at different levels of analysis. It is not wrong for some safety researchers to focus on trying to understand the cognitive, emotional, physiological and social components of the individual worker, nor is it inappropriate for others to analyse organizational power structures, hierarchies, systems, engineering practices or regulatory philosophy.”* (Flin, 2019, 255).

If it is not wrong to study different slices of the same topic, the issue becomes one of knowing whether these slices can converge towards a higher view of the subject which would be helpful to grasp its multifaceted nature as argued by Hollnagel above. In this respect, Roberts suggest that *“a useful activity might be to catalogue the most commonly discussed issues in this general area perhaps arraying them along a micro to macro dimension.”* (Roberts, 2019, 283).

Weick concurs but warns *“that in itself can be a strength depending on the uniqueness and overlap of the fragment. The context within which that claim holds true is Donald Campbell’s (1969) “fish*

scale model of omniscience.” He describes the model this way. “The slogan is collective comprehensiveness through overlapping patterns of unique narrowness. Each narrow specialty is in this analogy a fish-scale...Our only hope of a comprehensive social science, or other multiscience, lies in a continuous texture of narrow specialties which overlap with other narrow specialties” (Weick, 2019, 308).

How to ensure the quality of this overlap is a challenging task, but one important move is made when, first, traditions are identified, acknowledged and delineated in their diversity, and, second, their compatibilities but also incompatibilities are explored, debated and established (empirically or conceptually). Converging, in this context, would avoid the drawback of merging which makes no sense while at the same time, respecting the process of diverging which is an unavoidable outcome of specialising which has also its virtue (table 2, see Le Coze, 2019d for a more thorough discussions on the strengths of traditions, but also their complementarities, comparing high reliability organisation and resilience engineering). If this task surely is a complex one, I would like to shortly suggest Hopkins’ work as an example of converging strategy in safety research.

2.3. Converging, an example

Hopkins has been involved in safety research for more than 40 years and mainly known through his widely read accounts of disasters over the past twenty years. But, as argued elsewhere in more details than can be done here (Le Coze, 2019e), what has not yet been much revealed is the extensive methodological, theoretical but also comparative work involved in these several decades of research by the author. This, in my view offers an illustrative case of convergence, but mostly, **at least empirically**, in retrospective analyses of events.

Applying initially a sociological mindset based on a broad, Marxist view of societies, Hopkins has articulated several layers of analysis together, refining over the years his models. A close look at this process shows that Hopkins borrows and articulates ideas from a diversity of traditions identified above to provide an explanation for disasters which is practically and normatively oriented. His analysis is structured by what could be called a search for the conditions of an alignment between features of the environment, organisations and practices in order to promote safe operations (figure 1).

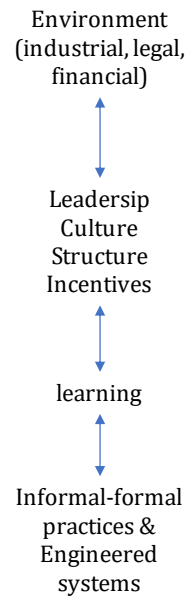


Figure 1: Aligning features of high-risk systems for safety

Engineering, technology, communication, informal practices, structure, culture, incentives, learning, leadership and environment of organisations have to be aligned to ensure safety, as follows. Structures of organisations must be designed by leaders to ensure that safety is granted enough weight in decision making processes, at the highest level and throughout the entire organisations. This is a design choice that mindful leaders must apply and which should work in practice well enough. These structures should also be based on incentives which convey the right message about what is expected in terms of safety, compared to other conflicting goals of the corporations.

In order to appreciate the level of achievement in practice of these design choices, learning should be at the heart of how leaders manage their business, an issue which questions the quality of communication and flows of organisations within the corporations. Indeed, informal practices which contribute to deviate from safe performance (performance which have to be defined by sound engineering based on risk analysis) must be identified through these learning processes, including reporting system and audits.

Organisations' environments, whether industrial, legal or financial, have to be supportive by providing adequate industry standard of practices, resourced regulatory regimes with competent inspectorate combined with a justice system which contributes to send signals to powerful actors that their lack of commitment to safety will be punished and finally, by realistic return on investment expectations by shareholders.

With this author, the different traditions identified above (table 1) have been to a certain extent explored, discussed, debated, used and sometimes rejected in his own developments because

they do not correspond to his mindset and personal sensitivity as a sociologist. When reading Hopkins' production, one can therefore see his position in relation to the ideas of authors situated in the traditions identified above (table 1). Let's mention, as examples, his rejection of the normal accident thesis (Hopkins, 2001), his support to and use of the high-reliability organisation **studies** (Hopkins, 2009) and his critics of what he describes as the anarchist school derived from the human error, interface design and system safety tradition (Hopkins, 2019).

The resulting model is a sophisticated perspective on safety, borrowing and articulating insights from different research traditions, embracing the multifaceted nature of safety (figure 1). Considerations about states, law, civil society, justice, organisation, structure, culture, informal practices, learning, power developed independently in separated traditions but articulated in one model is an innovative contribution not incompatible with previous attempts to link explicitly several (micro-meso-macro) levels of explanation (Vaughan, 1999).

It is also highly compatible with the very influential and popular graphical sociotechnical view of Rasmussen, and Hopkins uses in several occasions the Accimap layout (Rasmussen, 1997), while being more analytically specific from a sociological point of view, and empirically more grounded through detailed retrospective case studies (Hopkins, 2000). **But the value of Hopkins work is also in my view, from a converging perspective, to find a way to be both relevant to practice and theory, one core problem in safety research (Reiman, Kaupo, 2019, Shorrock, 2019,).**

Ethnographic safety models are powerful ways of keeping in touch with complex social realities but not applicable without translation by practically oriented readers (see the case for disaster studies by Hayes, 2019), while normative and performative models have the virtue of being appealing to practitioners but can have a dubious and complex relationship with reality (see Bergstrom, 2019 on resilience and just culture, and Waring and Bishop, 2019 on the relationships between safety constructs and professions in healthcare). One problem is when one does not to see the value and drawbacks of different approach, and one restricts relevance to only one type of approach. Safety science needs both, and Hopkins' narrative structure of his accounts of disasters creates a bridge while promoting a convergence strategy as defined in this article. Hopkins' model of safety made visible through a thorough historical and analytical examination of this author's work is however extremely challenging when moving from the retrospective and normative to the descriptive and daily operation of high-risk systems. It is all the more challenging in a world of fast pace of change, a problem to which **we turn next we treating the third theme of the special issue.**

3. How is safety globalised?

3.1. Keeping up with change

When one thinks of emerging risks, the first thing that comes to mind is technology. We know that with nuclear power plants, trains and planes came explosions, derailments and crashes, so any new technology can also convey a potential for catastrophes, depending obviously on its nature. But the past decades also sensitised us to the possibility of organisational accidents (Reason, 1997), namely the strong awareness that safety lies also in the ability of organisation to remain within the boundaries of safe performance. This problem has increased in our current interconnected global world. Let's elaborate.

One emerging risk for the future of safety science is **indeed** to fail to describe, to understand then to manage **new organisational- sociotechnical** configurations **created by these multiple kinds of interconnections**. These new configurations can be triggered by new technologies, but not only, and innovation in organisational and regulatory design can also be a reason to worry. For instance, if we follow Hopkins' model of safety **shortly introduced above and** combining several layers of analysis together (e.g. states, law, civil society, justice, organisation, structure, culture, informal practices, learning, power), how do we keep up with changes when these changes affect all of these different layers simultaneously?

The task is daunting empirically and theoretically, especially for studies **of** daily operations rather than in retrospect. These are multilevel research challenges (Le Coze, 2019f). One reason is that forces of globalisation over the past two to three decades have reshaped the operating landscape of high-risk systems, but that safety science has not yet fully adjusted accordingly its lenses to grasp the complexity of these processes and their implications, at least from a broad perspective supporting a convergence strategy. Many trends, propelled by globalisation discourses and policies have restructured flows of people, goods, ideas, images, capital, money in ways that are non-linear, diverse, non-deterministic and very contrasted. They can show positive as well as negative sides.

Globalisation has been propelled two to three decades ago by a combination of liberalisation of trade and finance, privatisation and deregulation but also two technological revolutions, one of information and communication (ICT) the other of transport (maritime, aviation) (Sassen, 2007). These forces do not operate to the same extent all around the world and there are many different regional and national situations, in the current situation of a shift of the world economy which include new powerful nations in Asia, South America and Africa (so called BRICS). This shift redefines the contours of globalisation as we have experienced it so far (Ruet, 2018), but how to study safety in this context?

3.2. Studying and understanding globalised safety

One proposition is to unpack the processes associated with globalised forces with the help of a number of trends which have affected safety-critical organisations but which have remained unproblematised in safety research when considered all together, with a converging orientation. These trends are both interwoven drivers and products of globalisation that have reshaped and are currently reshaping the operating landscape of high-risk systems: digitalisation, externalisation, standardisation, financialisation and self-regulation (figure 1, Le Coze, 2017). A brief overview of these trends is now sketched.

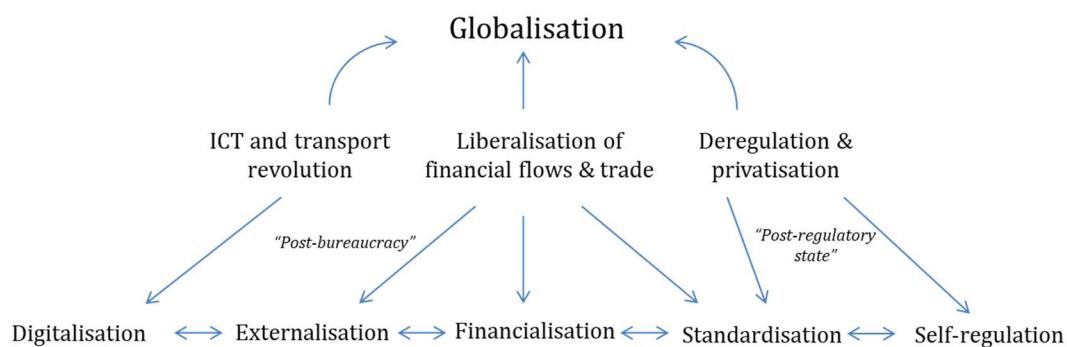


Figure 1. Globalisation, trends and safety (Le Coze, 2017)

Digitalisation through ICT supports and amplified by globalisation through the extended possibilities it offers to connect people across continents. Externalisation of activities for companies, enabled by the transport and ICT revolutions but also the liberalisation of trade generates global production networks (Dickens, 2015) or global value chains operating across continents (Ponte, Gereffi, Raj-Reichert, 2019). Standardisation is a product of deregulation, privatisation and the liberalisation of trade and finance which require both standardised practice and external auditors to certify expectations in terms of quality, safety etc between contracting businesses.

Financialisation, pushed by the liberalisation of finance, the ICT revolution, privatisation and deregulation, has reshaped the strategic context of businesses (return on investment driving short-term objectives of strategies) while self-regulation propelled by deregulation and privatisation has been also a pervasive trend affecting the relationship between states and businesses at the expense of the old prescriptive legal state-centric approach.

From a safety point of view, these transformations are massive. Thus, and as Pidgeon writes, *“it seems unlikely that industrial safety practice can remain completely insulated from these major global developments. This in turn sets a research agenda to fully understand the ways in which*

safety is indeed being impacted, and an immediate challenge to respond with new approaches and methods of risk governance” (Pidgeon, 2019, 266).

These massive changes constituting the background of safety can be illustrated by some high-profile events in the past decades which connect quite well with the trends sketched here and their associated implications. For instance, the story of BP (Bergin, 2012) in the first decade of the 21st century reveals strategic moves in a context of liberalisation of trade and finance, of ICT and deregulation (particularly in US) which led to catastrophic outcomes. These moves are best understood when the trends identified above are explicit. The BP case is one of a privatised ex-public owned multinational company which failed to balance its growth through merger and acquisition (M&A) and cost-cutting policy through decentralising its organisational model to satisfy financial markets.

Another example of the influence of these globalised processes in another industry is the Rana Plaza disaster in Bangladesh in 2013 (Taplin, 2014). The collapse of a building due to a fire in a country with poor regulations is attributed to the structural problem of powerful actors **in global value chains or global production networks** externalising their manufacturing to lower labour costs countries (Blair et al, 2013). Here again, liberalisation of trade and finance, ICT and transport revolutions combined with privatisation to create unsatisfactory conditions for safety in the industry of fast-fashion (namely short cycles of new clothes production). Globalisation offered multinationals opportunities of development through new organisational configurations (a decentralised system for BP, an unbalanced chain of commodity in the garment industry for the manufacturer in Bangladesh) combined with regulatory blind spots in these two case studies, in US (BP) and Bangladesh (Rana Plaza).

In the same vein, commenting on these trends, Pidgeon’s provides an analysis of Grenfell, another fire of a building this time in UK in 2017. *“In the UK, following the initial privatizations of the 1980s and the further acceleration of fiscal austerity measures from 2010 onwards, local authorities had sought to aggressively cut their costs, whilst at the same time outsourcing many building and maintenance contracts (e.g. for refurbishment). At the same time many of their internal building engineering departments were downsizing in capacity or disappearing entirely (Blockley, 2018), and in ways that may well have compromised their ability to fully evaluate and assess construction and other building risks. One can hypothesise here, and with good reason, that the local authority involved with Grenfell did not particularly want to scrutinise, or were not even in a position to properly scrutinise, the small cost savings achieved by adopting more flammable cladding as against the increased risks of uncontained fire spreading quickly (Pidgeon, 2019, 277).*

To keep the value of a converging model such as Hopkins’ one in a globalised context, **and for the study** of daily operations, it is therefore important to pursue the type of program that Schulman

describe as “*higher resolution*” program (Schulman, 2019). Such a research program extends the scale, scope and timeframe of the high-reliability organisations traditions. In the context sketched above, digitalising practices, externalising subcontracting activities, financialising strategies, standardising work and self-regulating businesses operate at several scales and have indeed multiple consequences and implications which depends on the extent, intensity and combination of these trends in diverse geographies and their interactions.

This is a kind of reset of our ways of apprehending safety. How, if we come back to the converging example of Hopkins’ model, several questions arise. Do we grasp the degree of alignment for safety between its multiple perspectives (states, law, civil society, justice, organisation, structure, culture, informal practices, learning, power) in the context of these globalised trends? What about the evolution of the role of states? What about informal practices in standardised and digitalised contexts? What about power relationship in a digitalised, algorithmic, environment? What about organisational structures in global production networks? And what about learning within these configurations? And most importantly in a converging strategy, how do these different issues interact?

A first **step towards converging** is to identify studies connected to different traditions, **as done during the 2017 Paris workshop**, which analyse **independently** the implications of these trends, by, for instance, studying increasingly mediatised working situations at the sharp end of safety-critical organisations (e.g. sensework, Haavik, 2019); exploring regulations as they face new technological developments and global processes (robust regulation, e.g. Engen, Lindøe, 2019) or also; considering how organisations evolve with the increase of standardisation combined with digitalisation (e.g. Antonsen, Almklov, 2019).

Engen and Lindøe ask for instance “*Do the different national regulatory styles still have comparative advantages in securing a robust safety level in their respective national industrial context? What are the challenges, and what are the possibilities? Moreover, how does globalisation affect the interrelationship between national political goals, economic requirements and the specific regulatory regimes?*” (Engen, Lindøe, 2019, 57).

Almklov and Antonsen writes “*we noted that one of the key features of the deregulation and outsourcing-based organisational changes was that coordination increasingly relied on market-based or transactional standardisation (...) digitalisation of work-control mechanisms will involve transferring some functions and decision-making authority to predefined algorithms, or machine learning, where human decision making is reduced to minimum*” (Antonsen, Almklov, 2019, 14).

In their studies, these writers raise important questions, and a first step could be to try to map several areas which stems from various traditions (along various micro to macro scales, see

Roberts' quote above) but what we also need for the future is therefore ambitious programs, "*to embrace multiple perspectives in a comprehensible way*" (Hollnagel, 2019, 266) in order to understand how these processes globally operate. Note that in this quote the imperative of being comprehensible is a very demanding task considering the extent, scope and scale of the patterns involved.

This brief description of such macro or mega challenges is only one aspect among other future challenges of perhaps unprecedented scale if one considers (but only mentioned here for space constraints), the ecological changes triggered by human activities (Le Coze, 2018). One gathers from this that there should be multiple opportunities in the future to think within, across and beyond research traditions through a combination of divergence and convergence, to tackle these emerging risks in safety science¹.

Conclusion

This article combines the three suggested themes of the special issue: history and evolution of safety science (theme 1); new models, processes and theories in safety science (theme 2) and emerging risks in safety science (theme 3). For theme 1, the article challenges the often-purported evolution in three stages or ages of safety. Considering the persistence of traditions but also their historical parallel developments over more than four decades, it seems doubtful that a neat distinction could or should be maintained. Technical, human and organisational safety have, from the point of view of research or practice, had far more mixed and concomitant contributions over the past decades, strengthening their legitimacy through diverse traditions.

Research traditions are introduced as a way of refining this view of the past, showing the many nuances between various authors who, through their work, strongly influenced our contemporary situation in safety research. There are many ways of understanding safety, and a classification grouping seven traditions is proposed: first, incubation, safety culture and learning, second, high reliability organisations, third, normal accident and the critical perspective, fourth, safety regulation and socio-legal perspective, fifth, a socio-constructivist perspective, sixth, safety climate, leadership and management, then finally, human error, interface design and system safety.

This compels researchers to pursue (and that is the second theme of this special issue dedicated to new models, processes and theories) empirical and theoretical work which would consider an option of convergence instead of divergence in the safety field. Divergence is a normal outcome

¹ I have developed and articulated these challenges in a revisit of Normal Accidents by Perrow (Le Coze, 2020).

of specialising in science (as attested by the enduring existence of traditions) which has its virtue, but one which could be complemented by convergence, favouring multi then interdisciplinary attempts, an example of which can be found in Hopkins' converging, retrospective, practical and normative model of safety.

This idea is all the more relevant that many safety issues are now and have been for the past decades globalised, although without research in this area fully adapting its methodological, conceptual and empirical lenses to capture the implications of the associated trends. Emerging risks, the third theme of the special issue, could correspond to these changes of the operating landscape of high-risk systems created by powerful trends such as digitalisation, externalisation, standardisation, financialisation and self-regulation in the contexts of **increasing flows and interconnections** which can escape the scrutiny of researchers, managers and regulators, and lead, from time to time, to disastrous events.

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