



HAL
open science

Safety science: A situated science

Corinne Bieder

► **To cite this version:**

Corinne Bieder. Safety science: A situated science. Safety Science, 2021, 135, pp.105063. 10.1016/j.ssci.2020.105063 . hal-03040731

HAL Id: hal-03040731

<https://enac.hal.science/hal-03040731v1>

Submitted on 15 Dec 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

1 Safety science: a situated science

2 An exploration through the lens of Safety Management Systems

3

4 Corinne Bieder

5 ENAC (Ecole Nationale de l'Aviation Civile), University of Toulouse, France. Email: corinne.bieder@enac.fr

6

7 *Abstract*

8 A number of key concepts have punctuated the development of Safety science. Reflecting on what
9 the next ones could be is a tricky exercise. How come certain safety concepts or theories or
10 dispositive in the sense of Foucault emerge and become 'dominating concepts' or turning points in
11 safety science? The paper considers a case from the past, namely that of Safety Management System
12 (SMS), as a proxy to shed light on this question. The origins of SMS are explored to unravel what lies
13 behind its emergence and development. The research is based on a literature review and open-
14 ended interviews of 15 people who played a personal part in safety science or practices development
15 before and/or when SMS started to emerge. Overall, the sample of interviewees represents a range
16 of safety stakeholders (academia, industry, regulatory bodies, consulting companies) and high-risk
17 industries to provide a diversity of perspectives on the emergence of SMS. The analysis of this
18 material highlights several aspects that contributed to converge towards an approach like the SMS,
19 beyond the identified limitations of safety science at that time. First, the intellectual context in which
20 SMS emerged, was that of major developments on organizational and managerial dimensions of
21 safety. Second, most safety stakeholders had motivations beyond safety enhancement to move
22 towards a new approach. Last, the overall environment, way beyond safety and high-risk industries,
23 facilitated the convergence towards an approach like the SMS. Eventually, this research
24 demonstrates that safety is a situated science, situated not only in time, but also in a much wider
25 economic, industrial, political, societal context. Putting safety into such perspective opens new
26 avenues for reflecting about the future of safety science considering current trends not only in safety
27 but also way beyond.

28 *Keywords*

29 Safety Science; Safety Management System (SMS); Societal context; Enabling context

30

31 Introduction

32 Reflecting about the future of safety science is a tricky exercise. Although one can have a
33 performative approach to the description of a possible future, it partly denies the existence of
34 uncertainties, at least the temporal uncertainty (Rowe, 1993). In the case of safety science, the
35 diversity of views and developments adds on to the challenge intrinsically related to that of
36 anticipation, when it comes to reflecting about its future. Indeed, without entering the debates
37 around the scientific validity of safety science, largely addressed in the special issue of *Safety Science*
38 of August 2014 and in the “founding fathers’ retrospection” (Stoop et al., 2017), safety science
39 cannot be considered a unified science where there is an overall or even some kind of wide
40 consensus on concepts, theories, models or tools (Ge et al., 2019).

41 From a historical perspective, several major turning points triggering new eras of safety science
42 development were identified. Dekker (2019), for example, highlights eleven turning points since the
43 beginning of the last century, each characterized by a dominating trend or concept. Just to mention
44 the past three decades, the author identifies, “Swiss cheese” and “safety management” as
45 dominating concepts in the 1990s, “safety culture” in the 2000s and “resilience engineering” in the
46 2010s. However, even if new ideas, approaches or theories were indeed advanced at some point in
47 time, in practice, research is still ongoing on most of the founding concepts and theories that
48 emerged decades ago, such as High Reliability Organization that appeared in the late 1980s or
49 “system safety” in the 1950s/60s. A variety of safety science schools of thought and practices keep
50 existing and developing in parallel. In addition, depending on the industry, and /or the applicable
51 regulatory requirements and regimes, different directions are explored to enhance safety before
52 some of them become widely adopted with time and recognized as generic safety science
53 developments.

54 A number of needs and challenges are identified today by safety scientists or practitioners, in
55 relation to either the evolution of high-risk activities or the intrinsic characteristics of safety science
56 (Le Coze, 2019a). For example, complexity is currently identified as insufficiently addressed by safety
57 science be it that of technology, organizations or institutions for example (Stoop et al., 2017; Le Coze,
58 2019b; Schulman, 2020). In relation to complexity as well, but primarily operational complexity and
59 its contingencies, another major challenge widely acknowledged is how to cope with the unexpected
60 or being “prepared” to be unprepared (La Porte, 2020; Weick & Sutcliffe, 2016; Grote, 2015). With
61 the increase of security threats and the demonstrated coupling of safety and security, this question
62 becomes an even more burning issue and opens as well to a number of possible future developments
63 (Bieder & Pettersen, 2020). On the technological side, digitalization and the development of artificial
64 intelligence is another area that poses new safety questions and issues (Almklov & Antonsen, 2019).

65 Beyond the evolution of high-risk activities and the way they are performed, challenges intrinsic to
66 the current state of safety science are also pointed out by some authors. Schulman for example,
67 underlines the need to be more constructive and collectively cumulative as safety scientists
68 (Schulman, 2020). The challenges of getting different disciplines to collaborate with one another in a
69 highly transdisciplinary domain such as safety was also discussed by Le Coze (2019b).

70 This landscape of possible avenues to explore identified within the safety science community may
71 provide interesting insights as to future areas of research, but is it sufficient to anticipate possible
72 future major steps in safety science? How come certain safety concepts or theories or dispositive in
73 the sense of Foucault emerge and become ‘dominating concepts’ or turning points in safety science
74 as named by Dekker (2019)? Very little knowledge is available regarding this genesis and spreading of
75 new safety approaches. Yet, understanding why and how a new idea emerges at a certain point in
76 time and develops, to a point where it starts spreading widely, could help reflecting about the future
77 of safety science.

78 The work presented in this paper focuses on the emergence of one safety approach characterized as
79 a turning point by Dekker (2019), namely, Safety Management Systems (SMSs). SMS can be used as a
80 proxy for a broader reflection on safety science because: a/ it is commonly used in many high-risk
81 industries today (it is even often a regulatory requirement in highly regulated activities) and is still
82 considered a promising way forward safety wise. As an example, following the preliminary report on
83 the investigation of the two Boeing 737 MAX, the Federal Aviation Administration recommended to
84 reinforce the SMS for aircraft manufacturers¹. In that respect, the SMS provides some insights about
85 the safety science situation today even though safety science includes many other safety concepts,
86 theories and approaches, some of which are commonly used as well today, often in parallel with the
87 SMS when the latter is implemented; b/ it is an example ‘sufficiently’ from the past to have reached
88 the status of a ‘dominating concept’ in safety science considering the numerous traces of its reach
89 and penetration in many areas, especially the industry, regulation or academia. As such, it can
90 support a reflection about the future of safety science and the possible ‘dominating concepts’ or
91 turning points to come. At the same time, the advent of the SMS is ‘recent enough’ to allow for a
92 comprehensive investigation of its origins, including through the views of those who contributed to
93 or witnessed its genesis.

94 A Safety Management System is an approach to systematically manage safety. Although detailed
95 characteristics may vary from one high-risk domain to another, overall, all SMSs share the following
96 features (already present in Kysor’s papers in 1973): a/a definition of the organizational structure
97 that needs to be put in place to manage safety, including objectives, policies and accountabilities; b/

¹ <https://www.reuters.com/article/boeing-737max/faa-to-mandate-new-safety-management-tools-for-airplane-manufacturers-idUSL1N2D11CX>

98 analysis of operational risks; c/ a definition of a safety assurance process (including the definition and
99 implementation of risk control measures) to keep the risks at an acceptable level; d/ a risk
100 communication process.

101 This paper aims to add knowledge to the emergence of new safety approaches by investigating that
102 of Safety Management Systems (SMSs), first discussed in the 1970s and progressively adopted as a
103 new safety frontier in the 80s and 90s. In particular, the research sheds light on what motivated a
104 change of safety approach at that time, as well as what contributed to the convergence towards an
105 approach like the SMS. The results are then discussed in the light of today's context to draw some
106 lines of reflection about the future of safety science reaching beyond its current identified limitations
107 and needs.

108

109 [Literature review](#)

110 The history of safety science has been largely explored in the literature ((Swuste et al., 2016, 2018;
111 Dekker, 2019; Le Coze, 2019a). Different time frames and steps or turning points have been
112 considered with small variations from one author to the other. However, very little is explored
113 regarding how the new concepts, theories or dispositives appeared. Bourrier (2011) provides insights
114 on the genesis of the High-Reliability Organization theory through an ethnographic approach. The
115 author explores several dimensions: the founding fathers' and mother's profiles, the group's ways of
116 working and the intellectual context at that time (especially the paradox faced by the group when
117 comparing its field observations with what the recently published Normal Accident Theory (Perrow,
118 1984) would lead to expect). Nevertheless, such endeavors to understand what contributes to the
119 emergence of a new vision are extremely rare. SMS is no exception to that. Although the number of
120 publications on SMS has been growing dramatically over the past decades², most of them focus on
121 the definition of SMS, its characteristics, its implementation in a variety of domains, its evaluation.
122 Nevertheless, some insights are provided by Li and Guldemund (2019) from their extensive literature
123 review on the commencement of SMSs. They characterize the latter as the merging between an
124 insurance approach focused on risk management and an industrial approach focused on accident
125 prevention and the development of safety defenses. However, very little is said about what
126 contributed to this merging. The main argument advanced is the improvement of technology
127 inducing more complicated safety defences, thus requiring management systems to "implement,
128 maintain and update these" (Li and Guldemund, 2019, p.97).

² From 3 papers in the 1970s, the number went up to 228 in the 1990s and kept increasing exponentially with a total number close to 3000 publications as of mid-2019 (Source: Scopus using the keyword "Safety Management System").

129 More generally, the emergence of new concepts, theories or approaches is not a widely explored
130 area in safety science. From a broader perspective, Kuhn (1962) in his essay on the structure of
131 scientific revolution identifies as a driver for new paradigms the existence of anomalies or violation
132 of expectations, that is, facts that cannot be explained using existing theories or concepts. However,
133 besides the limitations of existing scientific developments as drivers for new paradigms, Kuhn also
134 acknowledges that the “conditions outside the sciences may influence the range of alternatives
135 available to the man who seeks to end a crisis by proposing one or another revolutionary reform »
136 (Kuhn, 1962, p. x). One important aspect in these outside conditions is the world of ideas available to
137 the scientists. According to the author, shifts in visions do not result exclusively from the genius of
138 individuals, be them called Aristotle or Galileo, but also from the world in which they were
139 immersed, especially, the intellectual environment and the knowledge available at the time. Without
140 being as far reaching as scientific revolutions, Jasanoff (2004) highlights that science is intertwined
141 with societal evolution. “Science and society are *co-produced*, each underwriting the other’s
142 existence” (Jasanoff, 2004, p.17). Therefore, exploring the societal context makes sense to
143 understand the genesis of scientific developments.
144 Closer to safety, other authors have pointed out the influence of the context on the development of
145 safety vision and approaches. Merritt & Maurino (2004) illustrate the role of cultural aspects but also
146 that of the resources available to perform research, not only the financial or technological ones, but
147 also the ongoing access to news ideas and theories (p. 176). The influence of the political context is
148 also emphasized, especially in relation to the emergence of the safety culture concept following the
149 Chernobyl accident (Dekker, 2019). More recently, when reflecting about the future of safety
150 science, Dekker (2020) makes a link between recent safety developments and neoliberalism,
151 highlighting the impact of the overall political, economic and social context on safety and its
152 evolution. In short, it seems that scientific developments may be influenced by a broader context
153 that reaches beyond the identified limitations and needs of the science itself.
154

155 Methods

156 To try and understand the origins and generalization of safety management systems (SMS), a
157 research was conducted based on a literature review and interviews of stakeholders who
158 participated in the emergence and spreading of SMS. As underlined by Descamps (2005), interviews
159 allow for reaching beyond the official, declared objectives and strategies of organizations. Besides,
160 although written sources present a rather linear and rational story, interviews give access to “the
161 complex interactions between the structure, the strategy, the actors and external environment
162 permanently changing” (Chandler, 1989, cited by Descamps, 2005, pp.578-579).

163 In total, 17 persons were interviewed between July 2018 and July 2019. They were chosen for the
164 personal part they played in safety science or practices development before and/or when SMS
165 started to emerge either in their own domain or more globally. Overall, the sample of interviewees
166 represents a range of safety management stakeholders, high-risk industries and countries to provide
167 a diversity of perspectives on the emergence of SMS. 4 interviewees were from regulatory bodies, 3
168 from high-risk industrial companies, 3 from academia, 2 from consulting companies on safety
169 management and 3 had hybrid profiles including two or more of these experiences either
170 sequentially or simultaneously. The interviewees came from 7 different countries from Europe and

171 America. 7 out of the 15 were already involved in safety in the 70s, 6 started in the 80s, and 2 in the
172 early 90s.

173 The interviews were open-ended interviews, lasting between one and three hours. They were
174 conducted in English for non-native French speakers and in French for the others. The interviews
175 were not recorded but extensive notes were made in real-time and were afterwards validated by the
176 interviewee.

177 A qualitative content analysis method was used to process the interview data since this historical
178 investigation didn't rely on *a priori* assumptions or theory (Descamps, 2005). Considering the limited
179 size of the sample, the analysis was still manageable without software assistance and was performed
180 manually. The analysis of these data led to characterize: a/ the intellectual context and background
181 in relation to safety when the idea of SMS started to appear; b/ the actors who played a part as well
182 as their motivations to move towards a new safety approach; c/ key aspects of the overall context
183 that facilitated the convergence towards an approach like the SMS.

184 Results

185 The intellectual context and background related to safety around the 70s

186 The SMS is not a revolutionary concept or dispositive that spontaneously appeared. Its emergence is
187 closely linked to the evolution of safety thinking. A number of ideas and practices in relation to safety
188 already existed in the 70s and even earlier, and the intellectual context was dynamic with number of
189 developments to better understand and address safety. Some of these developments were led by
190 the industry, insurance or consultancy business, others were more scientific, led by academics.
191 However, the boundaries are not always easy to draw for some key actors had a multi-fold activity.

192 The first publication mentioned in Scopus in relation to Safety Management System dates back from
193 1973 and appears in the *National Safety News*, a US National Safety Council publication. H.D. Kysor,
194 the author, is not an academic with a safety related background but rather an aeronautical
195 consultant. In his two papers on SMS, *Part I: the design of a system* (Kysor, 1973a), and *Part II: SMS*
196 *organization* (Kysor, 1973b) one can find most of the ideas that can be found today in SMS
197 requirements.

198 Within industry, the idea of safety management was introduced in the 1920s by Louis De Blois, safety
199 manager of Dupont, according to a kind of risk concept that he invented, based on the two principles
200 that "hazard is energy and management is responsible" (Academic 2, diverse industries, June 14,
201 2019).

202 Coming from a different perspective, that of insurance, the contribution to accidents of workers'
203 social environment (underlying human unsafe acts) was identified in the industry as early as in the

204 30s by Herbert Heinrich in the US. The analysis of the root causes of thousands of accidents
205 (workplace accidents) in the steel industry led him to develop the dominos' model and to derive
206 recommendations in terms of managerial practices. In the 70s, in the US as well, Frank Bird Jr.,
207 further developed and refined Heinrich's dominos' model, especially through the description of
208 managerial factors likely to lead to a human unsafe act (Bird, 1974). He then turned this model into
209 an audit tool to help managers self-check they were doing what was needed (or described to be
210 needed) to prevent accidents and associated losses. This audit model, called the International Safety
211 Rating System (ISRS), consisted of a practical tool, namely a series of questions that managers could
212 use to check whether they were covering all the aspects of management contributing to safety (or
213 modeled as such). According to one of the interviewees, "the ISRS had no scientific foundations. It
214 was just the codification of industrial practice" (Academic 1, diverse industries, September 11 & 20,
215 2018). Yet, its development was derived from the incident causation model he developed based on
216 the analysis of more than 1.7 million accident reports.

217 On the academic side, the interest in safety developed in the 70s and 80s to a point where dedicated
218 multi-disciplinary research departments and specific courses were set up for example at Delft
219 University in 1978 (Stoop et al., 2017). Along the same lines, the journal *Safety Science* was first
220 issued in 1976. Although safety approaches had so far mainly focused on technology and human
221 factors (understood essentially as first line operators' errors), Barry Turner, a sociologist, published in
222 1978 *Man-made disasters*, a book theorizing the organizational vulnerability to accidents. In his
223 book, Turner (1978) highlighted the existence of a long period of incubation before the occurrence of
224 an accident, during which the organization remains blind to all signs contradicting existing beliefs and
225 norms. This was the first account of an organizational contribution to accidents.

226

227 [Motivations for a new approach](#)

228 Although enhancing safety is an obvious reason to improve the way safety is managed, other aspects
229 and motivations come into play in the emergence of an approach like the SMS. This section explores
230 the motivations, including beyond safety itself, of the main safety management stakeholders for
231 moving towards a new approach.

232 [Academics: the limitations of an individual focus](#)

233 Among the main drivers for scientific developments in safety science at that time was a series of
234 accidents (e.g. Flixborough in 1974, Bhopal in 1984, Challenger in 1986, Chernobyl in 1986). Indeed,
235 the dominant accident models and safety thinking of that time, focused on technical and human
236 factors aspects, couldn't provide sound explanations of these disasters. The research environment
237 on safety evolved and can be characterized by several waves of developments emphasizing the role

238 played by organizations on safety. Several organizational angles were proposed to describe and
239 explain either accidents, or alternatively, how safety can be ensured. Social scientists adopting a
240 more qualitative and 'situated' approach based on field research work started to pay more attention
241 to organizations as contributors to safety or to accidents (La Porte, 1994; Vaughan, 1997; Perrow,
242 1984; Reason, 1990). Two distinct academic profiles can be identified, with different contributions:
243 psychologists such as Andrew Hale, Bernhard Wilpert or James Reason, extending their scope from
244 individual behaviors to organizations following major accidents becoming hard to explain on the sole
245 basis of individual behaviors; sociologists or political scientists, with two types of contributions. First,
246 the analysis of how high-risk organizations drifted and/or failed (Turner was a pioneer in this area).
247 For example, organizational mechanisms whereby deviance become normalized were described by
248 Diane Vaughan in 1996. Second, an analysis of how high-risk organizations successfully managed to
249 sustain a high-reliability performance like for example La Porte, Schulman and the whole Berkeley
250 school of thought on HROs in the late 80s, proposing the High-Reliability Organizations theory (La
251 Porte, 1996). The introduction of a more managerial-like approach in academic research,
252 emphasizing the key role played by management in ensuring working conditions preventing unsafe
253 acts can be associated with the development of the Swiss Cheese model by James Reason in the late
254 80s, and published his book on Human Error (Reason, 1990).

255 Insurance companies: better calibrating premiums

256 Beyond any ethical consideration, one of the stakes, especially for insurance companies, was the cost
257 of accidents. Therefore, safety management became a wider concern in the 70s for these companies,
258 especially in the US. Indeed, the main challenge was to calculate insurance premiums depending on
259 what industrials had in place to 'manage' safety in a societal context where companies needed to
260 subscribe a private insurance for there was no public insurance system in some states in the US at
261 that time. In such context, the insights drawn by Frank Bird Jr., originally an engineer and then a
262 safety manager in the steel industry in the US, led an insurance company to recruit him in 1968.
263 "What he had developed served as a structure to determine the level of risk of a company, thus its
264 insurance premium. Frank Bird tried to put criteria to determine this premium" (Consultant/industry
265 2, diverse industries, 21 December 2018).

266 Industrials: trauma, ethics and performance

267 On the industrial side, historically, part of the motivation for Dupont to enhance safety management
268 in the 1920s was the fact that "the factory of [the company] blew up regularly" (Academic 2, diverse
269 industries, June 14, 2019). Accidents were still part of the factors that led companies, essentially in
270 the mining, oil & gas, chemical, food processing industries to turn to Franck Bird Jr's consulting
271 company in the 80s and 90s. As mentioned by one of the former employees of this company:

272 “Their [the companies we were working for] initial motivation was often triggered by a trauma,
273 either internal or close to the company or experienced by one of the organization’s leader in his
274 previous company. The change to adopt the ISRS³ was not spontaneous, it was rather an
275 electroshock” (Consultant/industry 2, diverse industries, December 21, 2018).

276
277 However, other motivations were mentioned by the interviewees regarding the decision to develop
278 or adopt different approaches to further enhance safety in the 90s, including ethical reasons, beyond
279 the reduction of the costs associated with accidents.

280 As stated by one of the interviewees: “Management systems were already discussed at that time
281 internally. Chemistry was a leader in terms of safety and safety management. HSE⁴ as well as social
282 aspects were explicitly part of the values promoted by the company. It was agreed at the top level of
283 the company that people were working at [name of the company] to make a living, not to lose their
284 lives. It wasn’t just words.” (Industrial 2, chemistry, January 25, 2019)

285 In the 90s, other industries in different countries as well funded their own research and development
286 to further enhance their approaches to manage safety. It was the case of Shell in the oil & gas
287 industry wanting to develop their own methods to identify organizational contributors to safety and
288 performance more generally. Enhancing safety management was seen as a way to improve their
289 overall performance by some companies’ and formed part of their motivations to move towards a
290 new approach. In the case of the adoption of the ISRS, “safety was just a pretext. It consisted in
291 expecting from each manager to bring its contribution to the good functioning of the company and
292 to take his share of responsibility” (Consultant/industry 2, diverse industries, December 21, 2018).

293 In the nuclear industry where the main approach to safety was certification, EDF in France, as well as
294 the NRC (Nuclear Regulatory Commission) in the US, developed new HRA (Human Reliability Analysis)
295 methods to integrate ‘on-line’ safety management aspects and operating experience. Performing
296 these more sophisticated analyses would not only respond to the mandatory certification
297 requirements, but also, beyond the certification exercise, allow drawing useful insights to enhance
298 safety (Bieder et al., 1998; Cooper et al., 1996). In France, the trigger was a change in technology
299 with the introduction of computerized control rooms and the need to certify these new N4 reactor
300 types with these novel control rooms. These HRA developments were focused on enhancing safety
301 by design of a socio-technical system rather than by supporting managers in addressing safety.

302 [Regulators: overcoming the pitfalls of command and control](#)

303 Different motivations were also identified on the part of regulatory agencies, not all similar nor
304 synchronized in time. Coming from different regulatory regimes, several countries played an

³ The ISRS (International Safety Rating System) was a tool to support managers in managing safety developed by F. Bird Jr. and sold to industrials when he decided to set up his own consulting company after him years spent in an insurance company.

⁴ Health Safety & Environment

305 influential role in the development of a new approach to safety management, such as Norway
306 (especially the oil & gas industry there), the Netherlands or the UK.

307 The reconsideration of the 'command and control' model of regulation is dated back to the end of
308 the 60s. It translated into some influential reports such as the Robens Committee one in the UK
309 published in 1972 and criticizing the traditional regulation model, mainly a top-down one, or the
310 introduction of the "humanization of work" concept in the Netherlands inspired from the Norwegian
311 Work Environment Act published in 1977 (Aalders & Wilthagen, 1997).

312 The Norwegian Petroleum Directorate (NPD), established in the 70s to regulate and oversee the
313 emerging oil & gas activity, soon initiated reflections on the regulatory regime to be adopted in their
314 particular context where (Lindøe and Olsen, 2009):

- 315 - the Norwegian Work Environment Act of 1977, "the world's possibly most stringent labour
316 legislation" (*ibid*, p.432) was in place;
- 317 - the offshore industry was densely unionized "with extensive collective bargaining rights and
318 a comprehensive network of safety representatives" (*ibid*, p.432);
- 319 - two major accidents occurred (the blow-out on the 'Bravo' platform in 1977, the capsizing of
320 the 'Alexander Kielland' platform in 1980) showing the limitations of the regulatory regime in
321 place.

322 The NPD pushed for moving from a reward and punishment to a mutual understanding and
323 cooperation approach to safety regulation (Lindøe and Olsen, 2009; Hovden, 2002; Hovden &
324 Tinmannsvik, 1990).

325 This reflection initially gave rise to an Internal Control approach that was then extended to all
326 industries to overcome a double bind resources issue. The first issue is a qualitative one related to
327 the increase in complexity and automation in industry, making it hard for a regulatory agency to keep
328 up with. The second issue is a quantitative one since resources were becoming too limited to
329 continue traditional monitoring (Hovden & Tinmannsvik, 1990).

330
331 In the UK, beyond the Robens report, the motivation for regulators to change approaches (initially in
332 process industry) also came from doubts expressed by the civil society about the efficiency of
333 regulators with a series of accidents occurring in the 70s and 80s, but more generally about public
334 services as further detailed in the following section. In this context, beyond the enhancement of
335 safety, regulators had two major challenges, namely, protect their liability and demonstrate their
336 efficacy (Power, 2004). In rail, a similar need to change approaches was identified in the 90s
337 following a decade of mediatized accidents. "There were also a lot of rail accidents, or the media
338 were more focused on accidents whereas they were silent in the past". (Academic 2, diverse
339 industries, June 14, 2019). "There was a decision made by the secretary of state not to put a warning
340 system on trains before this series of accidents. They had made a quick calculation on the back on
341 the envelope and came to the conclusion that it was not worth it. The "Yellow book" which was their
342 basis to perform risk assessment in the 90s had led to calculations 'proving' that it was safe enough
343 as such. But then this series of accidents happened. This risk assessment approach based on
344 calculations was not working so well in rail" (Mixed experience 1, diverse industries, January 21,
345 2019).

346 In aviation in Europe, regulation was essentially based on certification. The need for moving towards
347 new approaches came even later, just before the turn of the 21st century, with the corporatization of
348 Air Navigation Service Providers in some countries like the UK for example in 1996. “The privatization
349 or corporatization of public services was a strong incentive to rule the economic and safety aspects
350 independently from one another. Economic aspect to make sure that the increase of profits wouldn’t
351 be done to the detriment of clients. Safety aspect to make sure that safety wouldn’t be sacrificed to
352 the benefit of other business indicators” (Regulator 3, aviation, February 20, 2019). Regarding how to
353 rule the safety aspects, the main push came from the UK. “The UK CAA Safety Regulation Group had
354 a vision of how the regulator should intervene, considering that they had an issue to remain
355 competent on technology and that they didn’t want to take the responsibility of a detailed
356 prescriptive and oversight approach. They were willing to focus the approval on the safety
357 management system rather than on operational aspects. They had had bad experiences.” (Regulator
358 4, aviation, February 25, 2019) “The UK was perceived as dominant. The chairman of the SRC⁵ came
359 from the UK. The head of the SRU⁶ came from the UK. The other countries didn’t have the
360 experience. They were not doing such thing in their countries.” Aviation relied on the railway
361 experience in the UK that went through the privatization experience earlier which led to learn the
362 hard way. “How this interface would work didn’t come from aviation in the UK. It came from the
363 experience in the railway industry after it was privatized in a context of a liberal political system and
364 more generally a certain vision of the world. The UK experienced a number of rail accidents which led
365 to the clarification of control functions, especially for safety” (Regulator 4, aviation, February 25,
366 2019). However, despite the early developments of safety management, the real push towards a
367 change in regulatory approach happened following the Milan Linate and Überlingen accidents,
368 respectively in 2001 and 2002, revealing that there were “organizational and oversight
369 shortcomings.” (Industrial 3, aviation, February 12, 2019).

370

371 [Civil society: a growing suspicion](#)

372 An interesting angle to understand the societal push towards a new approach to safety management
373 is provided by the ‘risk society’ theoretical perspective developed and addressed by Giddens (1990)
374 and Beck (1992). In this perspective, risk is seen as amplified by the post-modern era where risks are
375 spreading and amplifying due to industrialization, globalization and urbanization, created and
376 accelerated by human activities.

377 In the 80s, as described by Beck (1992), the consciousness of self-produced or manufactured risks
378 was increasing, creating enhanced public anxieties fueled by media. Likewise, the public defiance
379 towards the governmental institutions and experts’ opaqueness was growing at that time (Giddens,
380 1990; Beck, 1992; Hutter, 1997; Power, 2004). Indeed, the public started to realize that experts were
381 disagreeing and that governments were failing to act, not to mention a certain suspicion towards
382 science that also contributed to modernization, thus to the development of risks. Both the public and
383 the media were less willing to accept advice from experts or to rely on regulatory models that they

⁵ Safety Regulation Commission

⁶ Safety Regulation Unit

384 suspected were lacking knowledge about a growing number of risks. The public expected decisions
385 and demanded the right for considering decision-makers accountable (Power, 2004, p.14).

386 [An enabling overall context](#)

387 If most safety stakeholders had diverse motivations to move towards new safety management
388 approaches, it is worth wondering why Safety Management Systems turned out to be “the” most
389 relevant approach crystalizing the variety of interests at stake. Exploring the overall context beyond
390 safety itself in the late 70s and 80s when SMS started to largely emerge and be adopted provides
391 some insights.

392 [An injunction for transparent and efficient control](#)

393 A big wave of deregulation occurred in the 80s, driven by a concern with over-regulation of business
394 and uncontrolled costs of regulation which still left serious doubts about the efficiency of the
395 regulatory practices in place. The 70s and 80s were indeed decades of a number of major accidents
396 such as Flixborough (1974), Piper Alpha (1988), Herald of Free Enterprise (1987). The concern with
397 regulation and its efficiency was in fact much broader than safety. It led in the 80s to the advent of
398 the New Public Management in the UK.

399 The growing public injunction for transparency, control and accountability of public services was
400 identified as a driving force for the explosion of audits in the UK in the 80s, combined with the
401 evolution of the regulatory strategy towards a ‘control of control’ or oversight of internal control
402 strategy, not only in the domain of safety (Power, 2000). More generally, the move towards the ‘risk
403 management of everything’ is a way to define a structure of (apparent) control and accountability
404 that provides the reassurance called for by the public including regarding the governance of the
405 unknown (Power, 2004).

406 As characterized by Hood (1995), “the basis of NPM⁷ lay in reversing the two cardinal doctrines of
407 PPA⁸; that is, lessening or removing differences between the public and the private sector and
408 shifting the emphasis from process accountability towards a greater element of accountability in
409 terms of results.” (p.94). Progressively, the NPM model spread across the OECD⁹ countries even
410 though there were some variations in the way and pace at which the model was implemented (Hood,
411 1995). A similar wave was observed in other European countries and the US starting in the 80s,
412 emphasizing the cost issue (Hutter, 1997). Regulators were forced to legitimate their own activities
413 by demonstrating they were operating both efficiently and effectively, that is without wasting
414 resources and by proving that their activities were making a difference. They adopted a private
415 sector style of management and risk-based approaches allowing for benchmarking public sector

⁷ New Public Management

⁸ Progressive Public Administration

⁹ Organization for Economic Cooperation and Development

416 activities against private sector activities. These approaches not only incorporated a cost-benefit
417 approach, but they also had the apparent benefit of being 'objective' and transparent and perceived
418 as efficient to support resources allocation, tested and trusted by the business community (Hutter,
419 1997).

420 However, this apparent transparency reaches beyond the sole objective of legitimating regulators
421 activities. It also constitutes an alibi, a 'demonstration' that everything was done to prevent failure.
422 As such, it is a form of preventive accountability to avoid being blamed in case of failure (Power,
423 2007).

424 This societal context in the 80s/90s is not just valid in the UK as a consequence of 'Thatcherism', but
425 is rather related to the "organization of trust in modern societies and institutionalization of checking
426 mechanisms". (Power, (the audit society preface to the paperback edition in 1999, p. xvi)).

427 In this context, the generalization of internal control leads to a new balance between resources and
428 responsibility, more specifically to an evolution from detailed prescriptive laws and regulations
429 specifying the preventative measures to be implemented to more formal and calculative approaches,
430 that can be audited based on a generic structure to make them reasonably one-size-fits-all tools for
431 assessing a wide range of companies (Hale, 2003). The arguments put forward to support this move
432 were a combination of a systematic and verifiable way to work with safety, a management system
433 for safety, some leeway for each company to find their own solutions to safety & work environment,
434 a way to place responsibility to individuals, including managers and directors, and also a way for
435 fostering a dynamic approach and up-to-date solutions to safety problems (Hovden & Tinmannsvik,
436 1990). By making internal control or self-regulation a regulatory requirement, authorities foster the
437 generalization and further development by companies of internal control in a kind of ultimately self-
438 reinforcing mechanism (Power, 2007).

439 [The Quality Management wave](#)

440 Although "TQM's origins can be traced to 1949, when the Union of Japanese Scientists and
441 Engineers formed a committee of scholars, engineers, and government officials devoted to
442 improving Japanese productivity, and enhancing their post-war quality of life" (Powell, 1995,
443 p.16), it was introduced in the US in the 70s (when Japanese products penetrate the US market
444 and as well as a result of the impact of Deming, Juran and other authors' writing) and in the UK
445 in the early 80s with the objective to enhance product quality, hence ultimately productivity
446 (Martinez-Lorente et al., 1998). This quality management wave translated into the publication of
447 the ISO 9000 norm in 1987 and the voluntary compliance with this standard having no
448 authoritative power reflecting the evolution of the whole society towards increased
449 bureaucratization and blurred boundaries between 'public' and 'private' (Hibou, 2012). Quality

450 Management Systems started to be part of the organizational landscape. Although ISO standards
451 initially focused on quality, groups were set up in the 80s and 90s to extend the quality
452 management approach to environment and then safety.

453 The development of standards (under the lobbying of certification companies) led to a shift of focus
454 and understanding by some high-risk companies that saw in the standards not the minimum but
455 what needs to be done (i.e. something like the maximum), an external recognition or sign of safety
456 consciousness and a cheaper option than other in-depth analysis approaches. Therefore, a number of
457 industries that had adopted the ISRS initially developed at a time where there were no ISO norms,
458 mistook it for a management system and welcomed more standardized approaches. “Some
459 companies came to the ISRS although all they wanted was the score. They would get the scores but
460 not the actual outcome (...) The ISRS was also a matter of external acknowledgement/recognition.
461 Companies would display their certificate in a visible location on the wall. Getting an ISO certificate
462 was easier” (Consultant/industry 2, diverse industries, December 20, 2018).

463 This standardization was also a good opportunity for certification companies and emerging
464 consulting companies making of the compliance with standards a juicy business and cutting costs
465 paving the way to a “low cost safety management” (Almklov, 2018).

466 [A practical approach endorsed by safety science after the fact](#)

467 The role of management and organizations in safety was analyzed and highlighted within the safety
468 science community leading to a number of theories as described earlier. The academic topic of
469 research was safety management. Interestingly, the theories coming from social scientists were
470 descriptive and didn’t rely on a hierarchical control model, thereby failed to meet industrials’
471 expectations. As stated by one of the industrial interviewees: “The ISRS was attractive for [name of
472 the company] people for they had a scientific background and wanted a framed approach. There was
473 a control loop (each item was graded: operational, need to improve or non-operational) and it was
474 prescriptive” (Industrial 2, chemistry, 25 January 2019). Eventually, the SMS, as it emerged as a way
475 to account for the role of management in safety, doesn’t originate from scientific developments. The
476 SMS developed despite the absence of scientific evidence (Hovden & Tinnmansvik, 1990) significantly
477 driven by forces outside the safety science arena and was then tentatively addressed in this arena.
478 Put in one of the Academic interviewees’ words, “when SMS became an item, Academics wondered
479 how to do that” (Academic 2, diverse industries, June 14, 2019). Turning to SMS for academics was a
480 way to push scientific ideas on the role of management on safety but also a way to get funding. “The
481 industrials would listen to academic SMS people who moved where the money was” (Academic 1,
482 diverse industries, 11 & 20 September 2018).

483 [Discussion](#)

484 Although the SMS is considered a turning point in safety science (Dekker, 2019), its emergence
485 reflects and crystalizes the needs, trends and expectations of a global industrial, economic, political

486 and societal context, far beyond the thinking on safety of the 70s and 80s. The research reported
487 here highlights the plurality of dimensions that come into play in the motivations of the different
488 safety stakeholders to move towards a new approach. The main drivers are of very different natures.
489 They include more specifically: technological progress and its related effects such as the challenges
490 to keep up to speed with the pace of it, especially for regulators; the limitations of existing safety
491 concepts and theories to explain real events; the concern of industrials to improve their overall
492 performance in an increasingly competitive context. Besides these aspects calling for a new safety
493 management approach, the overall context fostered the convergence towards an approach based on
494 risk management and control. More specifically, among the key shaping factors were: the
495 generalization of total quality and quality management systems (originally to improve companies'
496 performance) ; the societal crisis of trust in public institutions and experts, but also in technology for
497 they increased the will to manage and control everything both internally and externally, using private
498 companies' approaches and tools (Power, 2004).

499 Of course, the research presented in this paper is limited to the genesis of the SMS, that is of one
500 safety 'dominating concept' in the history of safety science. The results would need to be
501 complemented through the investigation of other examples to come up with a more consolidated
502 framework to think and understand the emergence of safety science 'turning points'. Nevertheless,
503 the research outcomes lead to consider safety as a situated science; situated not only in time with a
504 certain state of knowledge and technology, but also in a broad multi-dimensional context,
505 characterized by certain world views, attitudes towards uncertainty, visions of trust and modes of
506 interactions. The results unravel especially the influence of societal expectations and pressures with
507 respect to technology and institutions as well as of industrial practices on the shaping of a widely
508 accepted solution. This broad framework of the development of safety science 'dominating concept'
509 invites to contemplate some of today's major trends that could constitute some of the conditions
510 enabling the emergence of future safety science turning points.

511 Technology naturally comes to mind with the increased digitalization and development of
512 technologies such as artificial intelligence and machine learning that pave the way for new
513 'operators' with unprecedented and evolving capabilities and new forms of 'autonomy'. Autonomous
514 vehicles, drones, robots are already starting to raise a number of safety issues including in relation to
515 regulation and governance (Macrae, 2019; Andrews, 2017). However, the impact of digitalization
516 reaches far beyond safety itself, transforming social interactions, the foundation of trust or even
517 making new sources of data (if not information) available and new processing possible, with a variety
518 of effects in many domains.

519 Another current trend could contribute to shaping the future of safety science is the observed
520 evolution of governance mechanisms whereby the civil society at different levels pushes to make

521 behaviors evolve whether or not it involves institutional reactions. These phenomena, of which ‘flight
522 shaming’ is an illustration, challenge still widespread models considering that government is the only
523 actor managing and organizing societal and political solutions. More generally, “the shift to
524 governance is best understood as response to new challenges, such as globalization, increased
525 international cooperation (such as the European Union), societal changes, including the increased
526 engagement of citizens and the rise of non-governmental organizations (NGOs), changing role of the
527 private sector, an augmenting complexity of policy issues, and the resulting difficulty in taking
528 decisions with confidence and legitimacy” (Renn et al., 2011, p.233), citing (Walls et al., 2005).
529 Matyjasik & Guenoun (2019) explicitly envisage the end of the New Public Management¹⁰ and the
530 possible emergence of new modes of governance, some of which build by the way on the new
531 capabilities offered by digitalization. The evolution of governance models at a global level may
532 significantly impact safety and drive for new safety science concepts. Indeed, as shown earlier, the
533 NPM played a key role in the emergence of an approach like the SMS, by calling for more
534 transparency, control and responsibility.

535 Climate change, and the generalization of public acknowledgement of the urgency to address it, is
536 another current trend to consider. Indeed, it may challenge the value of safety. It raises questions as
537 to the relationship between safety and climate change. For example, will they be considered
538 mutually reinforcing each other or competing with one another (and under what conditions) like
539 safety and productivity have been for a long time and still are in many organizations? Other growing
540 concerns raise similar questions as to their coupling with safety. It is the case of security for example
541 (Bieder and Pettersen, 2020) or more recently with the Covid-19 outbreak of health.

542 Many recent disasters include a large number of natural disasters or attacks (cyber or physical) or
543 more recently pandemics. Concerns like climate change, security or global health also induce a
544 societal evolution that may shape future safety science concepts, namely, the attitude towards
545 uncertainty. Whereas the society of the late 20th century was that of the risk control of everything
546 (Power, 2004), a number of mediatized events challenge this view and reveals the limitations of risk
547 control. It is the case of some extreme climate events like wildfires in California or Australia, or
548 security events like 9/11, the Paris attacks in 2015 or the Germanwings accident, or more recently of
549 the Covid-19 outbreak. These evidences that total risk control is an illusion call for the need to
550 develop strategies to live with uncertainty more than try and pretend to reduce it totally.

¹⁰ One of the enablers of the convergence towards the SMS.

551 Conclusions

552 The analysis of the genesis of SMSs, one of the 'turning points' in the history of safety science,
553 provides some insights as to the many aspects that contributed to the emergence of such a
554 'dominating concept'. It reveals the multiplicity of motivations of the various stakeholders to change
555 safety approaches, including beyond the enhancement of safety itself. Resource issues, global
556 performance improvement or liability for example are dimensions that were part of the motivations.
557 However, the convergence towards an approach inspired from industrial practices, based on the
558 clarification of responsibilities and risk management also results from an overall enabling context.
559 Indeed, the generalization of quality management systems and the development and spreading of
560 New Public Management contributed to shaping a safety management approach that would be not
561 only acceptable to all safety stakeholders, but also matching the political, economic and societal
562 environment of that time. As such, the SMS as a new safety science dominating concept is situated.
563 Although the detailed framework to understand the genesis of new safety science concepts would
564 need to be consolidated, the research invites to contemplate safety as a situated science. As such, it
565 opens new avenues for reflecting about the future of safety science considering today's world. It
566 leads to putting safety into a wider context and perspective, considering some current technological
567 and societal trends such as the generalization of digitalization, or the growing concerns about climate
568 change, or the increasing acknowledgement of uncertainties and the need to live with them calling
569 for other modes of governance. It also and maybe above all encourages to remain humble as to what
570 can be advanced about the future of safety science.

571 References

- 572 Aalders, M., & Wilthagen, T. (1997). Moving Beyond Command-and-Control: Reflexivity in the
573 Regulation of Occupational Safety and Health and the Environment. *Law & Policy*, 19(4), 415-443.
- 574 Almklov, P. G., & Antonsen, S. (2019). Standardisation and Digitalisation: Changes in Work as
575 Imagined and What This Means for Safety Science. *Safety Science Research: Evolution, Challenges
576 and New Directions*, 1.
- 577 Almklov, P. G. (2018). Situated Practice and Safety as Objects of Management. In *Beyond Safety
578 Training* (pp. 59-72). Springer, Cham.
- 579 Andrews, L. 2017. Algorithms, governance and regulation: beyond 'the necessary hashtags'
580 retrieved in October 2019 at [https://www.kcl.ac.uk/law/research/centres/telos/assets/DP85-
581 Algorithmic-Regulation-Sep-2017.pdf](https://www.kcl.ac.uk/law/research/centres/telos/assets/DP85-Algorithmic-Regulation-Sep-2017.pdf)
- 582 Beck, U. (1992). *Risk society: Towards a new modernity* (Vol. 17). Sage.
- 583 Bieder, C. & Pettersen, K.A. (forthcoming). Safety and security - synergies and tensions. Springer,
584 Cham.
- 585 Bieder, C. (1998). MERMOS: EDF's new Advanced HRA Method. *PSAM4*.

586 Bird, F. E., Cecchi, F., Tilche, A., & Mata-Alvarez, J. (1974). *Management guide to loss control*.
587 Institute Press.

588 Bourrier, M. (2011). The legacy of the theory of high reliability organizations: An ethnographic
589 endeavor.

590 Cooper, S. E., Ramey-Smith, A. M., Wreathall, J., & Parry, G. W. (1996). *A technique for human error*
591 *analysis (ATHEANA)* (No. NUREG/CR--6350). Nuclear Regulatory Commission.

592 Dekker, S. (2019). *Foundations of safety science*. Taylor & Francis. CRC Press. *Boca Raton*.

593 Descamps, F. (2005). *L'historien, l'archiviste et le magnétophone: de la constitution de la source orale*
594 *à son exploitation*. Comité pour l'Histoire économique et financière.

595 Ge, J., Xu, K., Zheng, X., Yao, X., Xu, Q., & Zhang, B. (2019). The main challenges of safety
596 science. *Safety science*, 118, 119-125.

597 Giddens, A. (1990). The consequences of modernity. *Cambridge, UK: Polity*, 40.

598 Grote, G. (2015). Promoting safety by increasing uncertainty—Implications for risk management. *Safety*
599 *science*, 71, 71-79.

600 Hale, A. R. (2003). Safety management in production. *Human Factors and Ergonomics in*
601 *Manufacturing & Service Industries*, 13(3), 185-201.

602 Hibou, B. (2012). *La bureaucratisation du monde à l'ère néolibérale*. Paris : La découverte.

603 Hood, C. (1995). The “new public management” in the 1980s: Variations on a theme. *Accounting,*
604 *organizations and society*, 20(2-3), 93-109.

605 Hovden, J., & Tinmannsvik, R. K. (1990). Internal control: A strategy for occupational safety and
606 health. Experiences from Norway. *Journal of occupational accidents*, 12(1-3), 21-30.

607 Hutter, B. (2005). The attractions of risk-based regulation: accounting for the emergence of risk ideas
608 in regulation. *Centre for Analysis of Risk and Regulation Discussion Paper*, 33.

609 Jasanoff, S. (2004). Ordering knowledge, ordering society. *States of knowledge: The co-production of*
610 *science and social order*, 13-45.

611 Kuhn, T. S. (1962). The structure of scientific revolutions. University of Chicago press. *Chicago and*
612 *London*.

613 Kysor, H. D. (1973). Safety management system. Part I: the design of a system. *National Safety*
614 *News*, 108-5, 98-102.

615 Kysor, H. D. (1973). Safety management system. Part II: SMS organization. *National Safety*
616 *News*, 108-6, 75-77.

617 La Porte, T. R. (1996). High reliability organizations: Unlikely, demanding and at risk. *Journal of*
618 *contingencies and crisis management*, 4(2), 60-71.

619 La Porte, T. R. (2020). Resilience, Reliability, Safety: Multilevel Research Challenges. In *The coupling*
620 *of safety and security* (pp. 7-13). Springer, Cham.

621 Le Coze, J. C. (Ed.). (2019a). *Safety Science Research: Evolution, Challenges and New Directions*.
622 CRC Press.

623 Le Coze, J. C. (2019b). Resilience, Reliability, Safety: Multilevel Research Challenges. In *Exploring*
624 *Resilience* (pp. 7-13). Springer, Cham.

625 Lindøe, P.H and Olsen, O.E (2009). Conflicting goals and mixed roles in risk regulation: a case study
626 of the Norwegian Petroleum Directorate. *Journal of Risk Research*, 12(3-4), p. 427-441

627 Macrae, C. (2019). Governing the safety of artificial intelligence in healthcare. *BMJ quality &*
628 *safety*, 28(6), 495-498.

629 Martínez-Lorente, A., Dewhurst, F. & Dale, B.G. (1998), 'Total quality management: Origins and
630 evolution of the term', in *The TQM Magazine*, Volume 10(5), 378–386

631 Matyjasik, N. (Ed.), Guenoun, M. (Ed.). (2019) *En finir avec le New Public Management*. New online
632 edition. Paris : Institut de la gestion publique et du développement économique
633 (<http://books.openedition.org/igpde/5756>>. ISBN : 9782111294493. DOI : 10.4000/books.igpde.5756).
634

635 Merritt, A., & Maurino, D. (2004). Cross-cultural factors in aviation safety. In *Cultural Ergonomics* (pp.
636 147-181). Emerald Group Publishing Limited.

637 Perrow, C. (1984). Normal Accidents, Living with. *High Risk Technologies (Basic Books, NY, 1984)*.

638 Powell, T. C. (1995), "Total quality management as competitive advantage: a review and
639 empirical study", *Strategic Management Journal*, Vol. 16, No. 1, pp. 15-37.

640 Power, M. (2007). *Organized uncertainty: Designing a world of risk management*. Oxford University
641 Press on Demand.

642 Power, M. (2004). *The risk management of everything: Rethinking the politics of uncertainty*. Demos.

643 Power, M. (2000). The audit society—Second thoughts. *International Journal of Auditing*, 4(1), 111-
644 119.

645 Reason, J. (1990). The contribution of latent human failures to the breakdown of complex systems.
646 *Phil. Trans. R. Soc. Lond. B*, 327(1241), 475-484.

647 Renn, O., Klinke, A., & Van Asselt, M. (2011). Coping with complexity, uncertainty and ambiguity in
648 risk governance: a synthesis. *Ambio*, 40(2), 231-246.

649 Rowe, W. D. (1994). Understanding uncertainty. *Risk analysis*, 14(5), 743-750.

650 Schulman, P. (2020). Integrating Organizational and Management Variables in the Analysis of Safety
651 and Risk. In *Human and Organisational Factors - Practices and Strategies for a Changing World*.
652 Springer, Cham.

653 Stoop, J., de Kroes, J., & Hale, A. (2017). Safety science, a founding fathers' retrospection. *Safety*
654 *science*, 94, 103-115.

655 Swuste, P., Groeneweg, J., Van Gulijk, C., Zwaard, W., & Lemkowitz, S. (2018). Safety management
656 systems from Three Mile Island to Piper Alpha, a review in English and Dutch literature for the period
657 1979 to 1988. *Safety science*, 107, 224-244.

658 Swuste, P., Van Gulijk, C., Zwaard, W., Lemkowitz, S., Oostendorp, Y., & Groeneweg, J. (2016).
659 Developments in the safety science domain, in the fields of general and safety management between
660 1970 and 1979, the year of the near disaster on Three Mile Island, a literature review. *Safety*
661 *science*, 86, 10-26.

662 Turner, Barry A. (1978). *Man-made disasters*. London: Wykeham Press.

663 Walls, J., O'Riordan, T., Horlick-Jones, T., & Niewöhner, J. (2005). The meta-governance of risk and
664 new technologies: GM crops and mobile telephones. *Journal of Risk Research*, 8(7-8), 635-661.