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Review

Good and bad reasons: The Swiss cheese model and its critics

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ABSTRACT

This article provides a historical and critical account of James Reason's contribution to safety research with a focus on the Swiss cheese model (SCM), its developments and its critics. This article shows that the SCM is a product of specific historical circumstances, has been developed over a ten years period following several steps, and has benefited of the direct influence of John Wreathall. Reason took part in intense intellectual debates and publications in the 1980s during which many ideas circulated among researchers, featuring authors as influent as Donald Norman, Jens Rasmussen, Charles Perrow or Barry Turner. The 1980s and 1990s were highly productive from a safety research point of view (e.g. human error, incubation models, high reliability organisation, safety culture) and Reason has considerably influenced it with a rich production of models, based on both research and industrial projects. Historical perspectives offer interesting insights because they can question research, the conditions of its production, its relevance and, sometimes, its success, as for the SCM. But, because of this success, critics have vividly argued about some of the SCM limitations, including its simplistic vision of accidents and its degree of generality. Against these positions, the article develops a 'critique of the criticism', and the article concludes that the SCM remains a relevant model because of its systemic foundations and its sustained use in high-risk industries; despite of course, the need to keep imagining alternatives based on the mix of collective empirical, practical and graphical research which was in the SCM background.

1. Introduction

Over the years, the topic of safety has developed to become a relatively autonomous field of investigation, while also clearly connected to other, more-established fields (e.g. engineering, ergonomics, management, sociology). The field has matured to encompass a diversity of case studies, conceptual developments and research traditions including, for instance, cognitive system engineering (CSE) and high reliability organisations (HRO), and many lessons can be learned from looking back at the history of safety research. Le Coze presented some in his series of 'legacy articles' centred on key writers in the domain, notably Jens Rasmussen (Le Coze 2015a), Charles Perrow (Le Coze, 2015b), Andrew Hopkins (Le Coze, 2019a) and Barry Turner (Le Coze, 2020). The benefits of taking a look back include, among others, gaining a better idea of how much progress has been made over the years, a better overview how some key issues and associated concepts structure the field, and an understanding of how these concepts emerged from their specific historical, scientific and social contexts (Swuste, 2016). A retrospective review can also help to identify unexplored territory and potential new developments and research avenues.

In this context, a key author is James Reason. Practitioners and researchers in the field of safety often refer to 'Reason's model', referring to Reason's 'Swiss Cheese' representation; as has already been suggested elsewhere, this is something of a simplification (Larouzée and Guarnieri, 2014). Ten years passed between the publication of Reason's first Organisational Accident Model (OAM) and his Swiss Cheese model (SCM). During this period, he released many alternative versions of his OAM, and many other related models. Although the SCM has become one of the most popular models for both practitioners and safety scientists (Underwood, 2013), it has also been widely criticised.

This article first briefly reviews the creation of the SCM. We follow the intellectual trajectory of Reason, to show how his thinking evolved from the study of sensory disorientation to that of human error in safety (1.1). We then show how the industrial and political context in the 1980s, together with the people he met led him to study and model organisational accidents (1.2). In the 1990s, Reason became increasingly engaged with industry and published different versions of his accident model, all of which bear traces of the evolution and refinement of his thinking (2.1). This historical analysis allows us to question the generally accepted idea that the SCM is Reason's only model.

At the same time we try to explain, with particular attention for metaphorical and graphic reasons, why the SCM has dominated other attempts to model accidents; both Reason's own efforts and the set of models adopted by people working in the domain (2.2). In a second step, we review the main criticisms of the SCM, distinguishing between those that relate to the foundations of the model (3.1) and those that relate to its representation or influence on practice (3.2). Finally, we

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discuss two motivations for these criticisms, the first from the scientific angle (e.g. epistemological, ontological) making up a discipline that gradually became autonomous and institutionalised; and the second related to economic and commercial issues (e.g. the search for private funding, consulting activities in industry). We conclude this historical study and review of the criticisms of the SCM by highlighting some of its strengths and underlining its systemic and contemporary character (3.3).

2. The genesis of a very successful model

In this section, we detail the stages of development of the organisational accident paradigm by studying Reason's publications from the early 1970s to the 2000s. We focus primarily on the graphical model that became the Swiss Cheese Model (SCM) and do not explore his other work, most notably his version of safety culture (Reason, 1997, 1998). We broaden the understanding of the SCM by identifying its historical genesis. The approach was based on the following steps. First, Reason's articles, chapters and books, published over several decades, were identified then analysed (Larouzée and Guarnieri, 2015). Second, we describe how his models, experiences and encounters interacted to create the conditions that led to the emergence of the SCM. Third, we present the various critiques of the model, with the help of an in-depth retrospective exploration of the evolution, content and intention of the SCM.

Fourth, we outline conversations between Reason, Wreathall and the first author of this article that offered new insights, and confirmed or challenged interpretations. The results of these first four steps were published in previous articles by the first author (Larouzée and Guarnieri, 2014, 2015). A fifth step consisted in situating Reason's work based on earlier epistemological, historical and conceptual studies in the field of safety, published by the second author (Le Coze, 2015a, 2015b, 2019a, 2020), including an earlier study of Reason's work (Le Coze, 2013).

2.1. Starting from the micro

James Reason was not particularly destined to become a safety scientist. After two years of medical studies, he reoriented his career towards psychology by focusing on sensory disorientation and motion sickness, the subject of his thesis (defended in 1967) and his first publications (14 articles and two books before 1977). These early works shaped his interest in the potential to deceive the human brain through the senses,[1] the starting point for his interest in the topic of error.

It begun with an experience from everyday life that struck the psychologist: "*One afternoon in the early 1970s, I was boiling a kettle of tea. The teapot (those were the days when tea leaves went into the pot rather than teabags) was waiting open-topped on the kitchen surface. At that moment, the cat – a very noisy Burmese – turned up at the nearby kitchen door, howling to be fed. I have to confess I was slightly nervous of this cat and his needs tended to get priority. I opened a tin of cat food, dug in a spoon and dolloped a large spoonful of cat food into the teapot. I did not put tea leaves in the cat's bowl. It was an asymmetrical behavioural spoonerism*" (Reason, 2013). Reason notes that his error was anything but random, as it was related to the similarity and concomitance of the two activities. Human error would become his field of research, at a time when very intense activity had been triggered by: (1) the consequences of the Three Mile Island nuclear incident in 1979; and (2) increasing concern about human-machine interactions in safety-critical systems (e.g. aircraft, nuclear power plants). One of Reason's main contributions was to bring together different lines of thought into a framework that would prove to be extremely useful. In particular, he successfully framed the complex cognitive processes that underlay the diversity of error types (as for instance in the development of an operational human error classification by Shappell and Wiegmann, 2000).

Reason was influenced by the work of Nooteboom (1980) on speech errors, Norman (1981) on types of errors and Rasmussen (1983, 1986) in the field of cognitive engineering. Adopting a naturalistic approach, he began to keep a record of his day-to-day errors and quickly involved his wife and students. He interpreted these error reports[2] using Norman's action theory, which distinguishes failures and mistakes, combined with the generic model of cognition created during the 1970s and early 1980s by Jens Rasmussen (Rasmussen, 1983). This choice followed a comparison of generic models of cognition available at the time (Reason, 1988). Rasmussen's model distinguishes three levels of cognitive activity: skill-, rule- and knowledge-based mental processes (SRK), and has become a standard in the field of cognitive engineering (Sheridan, 2017).

Reason defined error as "*a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency*" (Reason, 1990, p. 9). He regarded it as a sub-category of 'unsafe acts' that included slips and lapses that could occur during highly-automated (*skill-based*) actions, and *mistakes* related to failures planning of actions.

However, he added a very important element to this picture. Derived from the study of accident reports (including Chernobyl, see Reason, 1990) and the work of Jerry Williams (1996, quoted by Reason, 2006), he distinguished between *errors* and *violations*. The latter refers to voluntary transgressions of a rule or imposed procedure, which may be related to habits, a need (equipment or unsuitable work space, incompatible safety and production objectives, etc.) or acts of sabotage (intention to harm). This taxonomy translated into the visualisation shown in Fig. 1, and offered a much needed overview of the diversity of what, at the time, was simply a heterogenous collection of 'errors'.

Let's briefly comment this classification which framed a taxonomic view of the study of errors in comparison with a naturalistic one (Le Coze, 2015a). Reason describes himself as a naturalist, "*In my error collections, I didn't rely on experimental psychology—something I've always resisted: in order to do a sensible experiment in psychology, you have to try to control the related variables—and if you can do that, it can't be a very interesting experiment—yes, there's memory lists, perception etc. etc. And there are some brilliant experiments, but not many. If I had mentors, they would have been Darwin or William James, or Freud. I am by instinct a natural historian. I watch, collect, but rarely manipulate. I'm interested in the 'quotidien', the everyday, banal events of everyday mental life*" (Reason, 2015; personal communication).

It is interesting to explore this in more detail because, despite his naturalist sensitivity, he did not develop a strictly ecological view of errors. In this, he departed from work that relied on observations of experts in real-life situations, for instance Rasmussen's investigation of troubleshooting (Rasmussen and Jensen, 1974) or Klein, who initiated the field of naturalistic decision making (Klein, 1999). Rasmussen's naturalistic (or ecological) approach to errors led to him developing a different perspective on the relation between accidents, errors and organisations. In fact, as argued elsewhere (Le Coze, 2015a), when Reason and Rasmussen met in the 1980s, despite their similar interests, they found that their approaches diverged from both a micro and macro

[1] For example, by placing a subject in front of a screen where an infinite pattern moves vertically generating an illusory motion (similar to the illusion one experiences in a stopped train seeing another train moving), the deceived brain attempts to correct the posture and can ultimately lead to a fall (Reason et al., 1981).

[2] The aim was always to understand the nominal functioning of the brain: "*slips of action can provide valuable information about the role of conscious attention in the guidance of highly routinised or habitual activities by indicating retrospectively those points at which the attentional mechanism was inappropriately deployed*" (Reason, 1984a).

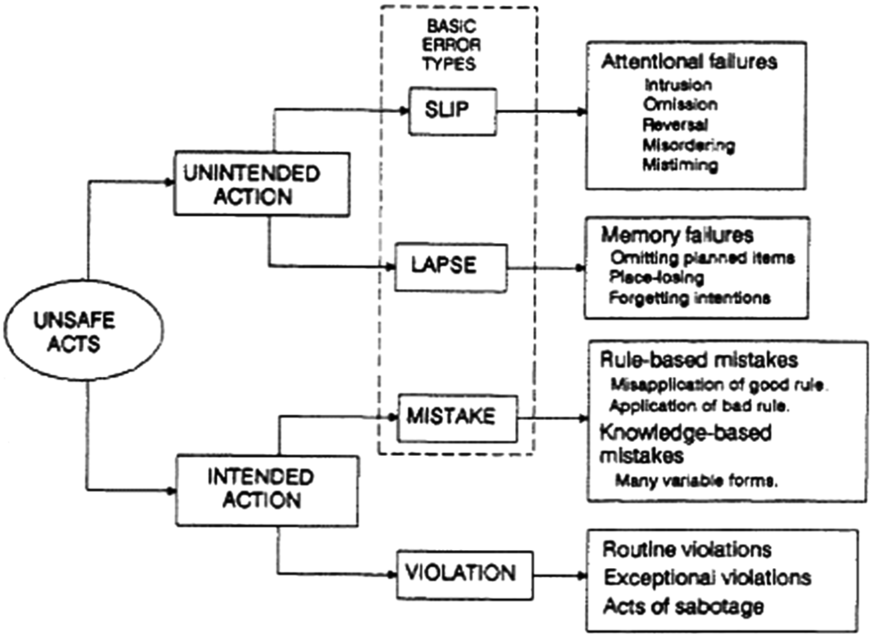

Fig. 1. Taxonomy of unsafe acts, distinguishing between voluntary and involuntary actions and the cognitive function involved (execution, memorisation, planning) (Reason, 1990).

point of view (more on this later).

This is not without implications, as different views of errors lead to different prevention strategies, as the resilience engineering school of thinking has argued (Hollnagel et al., 2006). In particular, developing a taxonomy of errors may orient prevention towards attempts to identify and then eliminate them. On the other hand, the ecological view sees errors as an adaptive feature of cognition. Eliminating them is unrealistic as, in complex dynamic situations, most of the time when they happen, it is possible to recover. In Reason's words: "*We cannot change the human condition, but we can change the conditions under which humans work*" (Reason, 2000).

2.2. Moving to the macro, towards the SCM

At the time when Reason was becoming interested in a psychological understanding of errors in relation to accidents (Reason and Mycielska, 1982; Reason 1984b) and in the process of writing a new opus, which became the acclaimed *Human error* (Reason, 1990), other works that adopted a sociological analysis were published; notably, Turner (1978) and Perrow (1984). In particular, in the 1980s Turner initiated a fruitful research program on the *incubation model* of disasters, with psychologist Nick Pidgeon and engineer David Blockley (for a history of this, see Pidgeon, 2010, on Turner, see Le Coze, 2020). This, without doubt, provided a stimulating background for Reason, as we know from Nick Pidgeon (personal conversation with second author), that they met at the time.

This organisational thesis of accidents was made all the more relevant by several disasters in the 1980s, including Bhopal (1984), Chernobyl (1986), Challenger (1986), Kings Cross (1987), Exxon Valdez (1987), the Herald of Free Enterprise (1988) and Piper Alpha (1988). It was also at this time that accident reports began to highlight the organisational dimension of such events (Reason, 1990). These documents underlined that human error, in itself, appeared to have limited value in making sense of the conditions that triggered disasters. It was clear that the circumstances went beyond an operator turning the wrong valve or pushing the wrong button, and it was in this context that Reason developed a graphical method to conceptualise organisational accidents. In the following sections, we describe the main steps that ultimately led to the publication of the SCM, namely the resident pathogens metaphor (developed by Reason), the idea of defence in depth (brought in by Wreathall) and the Swiss cheese analogy (proposed by Lee).

2.2.1. James Reason's resident pathogens metaphor

The *resident pathogens* metaphor[3] distinguishes between *active* and *latent errors*[4] (Reason, 1988). Like cancer or heart disease, industrial accidents result from a combination of factors, each of which is necessary but not sufficient to overcome the technical, human and organisational defences of the industrial system. Reason argued that the safety level of any organisation could be evaluated from a limited set of indicators, drawing an analogy with a medical diagnosis, which is based on a limited number of parameters such as heart rate and blood pressure. The metaphor formed the basis for several hypotheses (Reason, 1988):

- The more resident pathogens in a given system, the more likely that an accident will occur.
- The more complex the system, the more pathogens it can contain.
- A simpler system with poorer defences is more vulnerable to pathogens than a more complex and better-defended system.
- The higher the hierarchical level of an individual, the greater his or her potential to generate pathogens.
- The pathogens present in a system can be detected *a priori*, unlike active errors that are difficult to predict and are often found *a posteriori*.

Reason concluded that it was therefore more interesting to focus safety management efforts on the detection and elimination of pathogens than active errors. He noted that any accident analysis was likely

[3] The metaphor was inspired by his two years of medical school.

[4] This would later be termed *latent conditions*, on the advice of John Wreathall. The idea was to account for the fact that a decision could create latent conditions in the system although, in itself, it did not represent an error *per se* (interview with Wreathall, October 2014).

to reveal latent conditions: the deeper the investigation, the greater the focus on latent factors. Thus, the principal contribution of his metaphor is not to demonstrate the existence of latent conditions, but to suggest that they must be detected and addressed *a priori*. It is important to note that this proposition is not equivalent to determinist, accident proneness theory.[5] It should also be noted that the idea that there are permanent, latent conditions in the system refers to a micro view of human error, which sees accidents (human error) and safety (human performance) as two sides of the same coin. In this respect, Reason's graphical model is as much an accident model as a model of an accident.

2.2.2. John Wreathall's defence in-depth concept

Reason's work on the resident pathogens metaphor was reinforced by John Wreathall's work. Wreathall was a nuclear engineer, and the two met in 1981 during a conference on human error and safety.[6] One evening in 1987, their collaboration gave birth to the first OAM – on a paper napkin in a pub, "*Here is how I recollect the birth. John was staying with us, and I was wrestling with 'Human Error'. I was driven by the thought that in order to understand what went wrong, we should be able to say what ought to go right. That was when John started to draw overlapping planes, and I put in the holes*" (Reason, 2015; personal correspondence).

The engineer provided the psychologist with a normative model for any productive organisation. Five elements are present: political decision-makers (designers and senior managers), a managerial chain divided into departments (maintenance, training, operations, etc.), preconditions (trained and untrained operators, technology and equipment, future plans, maintenance, etc.), productive activities (synchronisation of operators and machines) and defences (technical, human and organisational). From this foundation, Reason attempts to describe where (a taxonomy of errors) and how (the resident pathogens metaphor) failures emerge and combine in a system, leading to an accident (Fig. 2a).

This is a particularly interesting aspect of the genesis of the SCM: it is clearly rooted in the '*defence in depth*' concept found in Wreathall's nuclear culture (Fig. 2b). The model's superimposed planes bring a sense of depth, which reflects the physical reality of designing software and hardware to prevent a catastrophic scenario (e.g. a condenser to cool down reactors, automatic systems triggered by pressure and temperature thresholds, highly confined spaces). By merging their views, Reason and Wreathall ended up with a model that extended these engineering concepts to the human and organisational domain (for a more detailed discussion of the percolation of the *defence in depth* concept into the SCM, see Larouzée, 2017).

Reason recognised that these ideas were a good fit with his medical metaphor and the distinction between latent and active failures. This new, powerful graphical representation expressed the idea of the percolation of the effects of managerial decisions (training, resource allocation, maintenance, etc.) into workspaces, ending with operator performance. Such decisions could have more-or-less direct effects on the integrity of the system's defences (poor maintenance, lack of training, etc.). The first layers in the model are managerial, the last operational and engineering.

2.2.3. Rob Lee's Swiss cheese metaphor

In 2000, Reason's article, *Human error: models and management*, was published in the British Medical Journal (BMJ) (Reason, 2000). This article was the first in a series devoted to medical safety. Aware that he was addressing a public that was less familiar with human factors than in industries such as aviation or nuclear power production, he published a simplified version of his OAM. This version represents the barriers in a system by slices of cheese, and their weaknesses by holes (Fig. 3). The idea had been proposed by Rob Lee in the early 1990s,[7] and partially exploited in a 1995 collective book on aviation maintenance (see Maurino et al., 1995; p. 25). The *Swiss cheese* model was born.

With these three, conceptual and graphical additions, Reason moved from his psychological, micro focus on human error and an acclaimed graphical taxonomy (Fig. 1), to a systemic, macro visualisation of accidents, leading to one of the most popular safety models (Figs. 2 and 3). This shift was partly based on discussions with both John Wreathall and Rob Lee. It was also influenced by reports into the major accidents of the 1980s, and sociological studies of organisations and accidents including, most prominently, Barry Turner and Charles Perrow. It is possible that Reason adopted the notion of an incubation period (developed by Turner) and turned it into the idea of resident pathogens; he also turned Charles Perrow's normal accident thesis into the problem of aligning holes in the defence in depth concept. But if the Swiss cheese model became the success we know today, this was less so for his other graphical models. The next section presents a selection of such attempts.

3. Other graphical explorations

Another interesting line of investigation, from a retrospective point of view, is the succession of graphical representations that Reason produced, but which proved less successful (Figs. 4–7). Like the legacy of Jens Rasmussen (Le Coze, 2015a), this work indicates his constant search for a more refined model that could accommodate new research findings derived from his consulting activities. In the case of Reason, this concerns, in particular, the development of the Tripod method.[8]

3.1. Constant evolutions

Throughout the 1990s, Reason released new versions of the OAM. Mk II (Fig. 4) explicitly mentions General Failure Types (indicators used in the Tripod method). This evolution in his thinking was initiated following a research partnership with a company. An alternative version of the Mk II model (Fig. 5; Reason, 1993) highlights the notion of latent errors 'spreading' through an organisation. In contrast, the Mk I model groups 'production management' and 'psychological precursors' into the 'workspace', which reflects the influence of local conditions on operator performance. Another, more significant development is the introduction of a separate path (bottom arrow, Fig. 5), which highlights the direct influence that managerial decisions can have on the integrity of barriers. The appearance of this path followed his study of many accident reports (e.g. Challenger), which showed that a catastrophe could occur in the absence of an active error, "*unsafe acts at the sharp end are not essential – though common – for creating defensive gaps and weaknesses*" (Reason, 2008; p. 99). A comparison of the Mk I OAM (from 1990) and two variants of the Mk II (one from 1993) documents the appearance, in Reason's mind, of concepts or representations from both research and industry.

[5] This theory is based on the work of Greenwood and Woods (1919, cited by Reason, 1990), who aimed to identify individual determinants that led people to be more likely to cause accidents. The theory was refuted in the second half of the twentieth century, following the expansion of human and organisational factor theory.

[6] The Three Mile Island accident (1979) motivated the organisation of these conferences. The book *Human Error* (Senders and Moray, 1991) is the only publication emerging from the conference held in 1981.

[7] At the time, Lee was Head of the Bureau of Air Safety Investigation at Canberra (Patrick Hudson, personal correspondence). The analogy with Swiss cheese was inspired by the circular holes in the alternative Mk I representation (Fig. 2b) published in 1990 (interview with James Reason, January 2014).

[8] This project was funded by Shell in the second half of the 1980s. Initially, Willem Wagenaar from the Safety Group of Leyden University was contracted. Wagenaar invited Reason to join the project, and the team included Jop Groeneweg and Patrick Hudson (Hudson et al., 1994). Fieldwork was conducted by Jop Groeneweg during his PhD thesis in 1992 (Groeneweg, 1992).

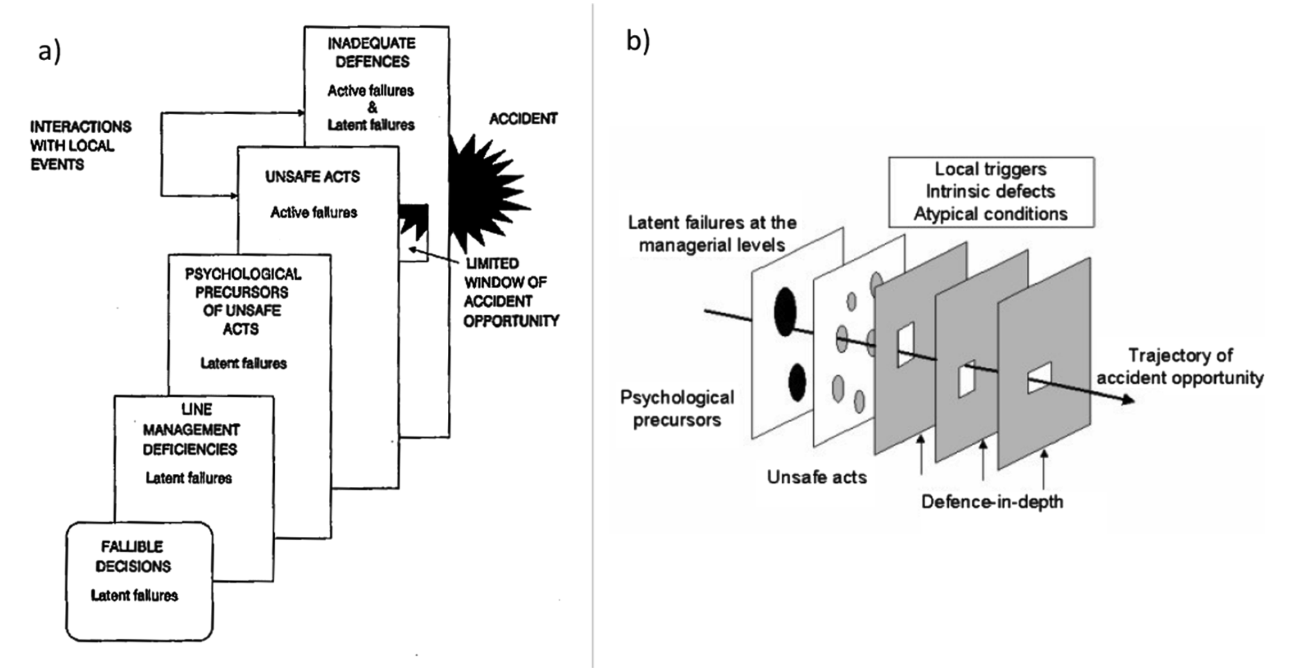

Fig. 2. First published versions of the OAM (a, b), combining a normative model of a productive organisation drawn by Wreathall and Reason's work on human error (1990). In particular, there is the first explicit mention of 'defence in depth' (b).

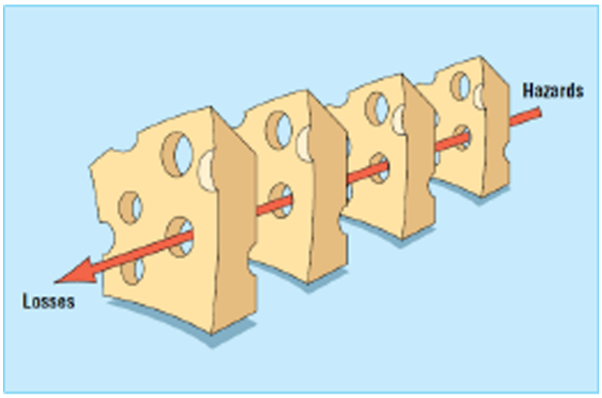

Fig. 3. The Swiss cheese version of Reason's OAM published in the BMJ paper (Reason, 2000). While the text of the article distinguishes between active and latent errors, this is not reflected in the diagram.

In 1995, Reason published a remarkable, alternative version of his OAM[9] (Fig. 6; Maurino et al., 1995). This vertically-oriented model presents two distinct failure pathways: one related to human errors and the other to barrier failure. The concept of *climate* appears: specific to the local workplace and likely to change quickly, it is distinguished from *culture*, which is influenced by high-level decisions and is more stable over time. The accident is presented as a "*loss of control over the risks causing damage*", 'loss of control' resulting from interactions between organisational processes, local work areas, defences, risky acts and latent conditions. The use of the term 'control' and the use of feedback (represented by double-headed arrows) clearly indicate a *systemic* stance (Hardy and Guarnieri, 2012). Finally, the vertical orientation does not suggest causality, but a rather structuralist vision of hierarchical relations between different levels of an organisation (Reason et al., 2006).[10] However, this version was quickly abandoned (as far as the author knows, it has not been quoted or used in any publication referencing or drawing upon Reason's work). It would be interesting to look at the reasons why it has been forgotten.

Two years later, Reason published a book addressed at safety practitioners[11] (Reason, 1997). Its cover shows a new version of the model (Mk III, Fig. 7), which presents the three basic elements of any accident: hazards or risks, defences and losses. The organisation is reduced to its defences, which are undifferentiated, "*it is often very hard to distinguish productive and protective system elements. Many sub-systems serve both goals (*e.g. *pilots, ATCOs,*[12] *train drivers, etc.)*" (*op. cit.*). Finally, factors that can alter defences are represented in terms of their remoteness (both spatial and temporal) from the adverse event, and their number, in any system.

This triangle suggests that although a single unsafe act can lead to an accident, many other organisational factors are involved. The model also benefits from Reason's long-term collaboration with Wreathall (via their joint consulting activities), seen in the replacement of the term *latent failures* (Reason, 1990) or *latent errors* (Reason, 1993) by the term *latent conditions* (commented on above). After the publication of the Mk III model, Reason turned his attention to safety culture. In 2000, he moved away from the industry (although never really left it), to work in the healthcare system. This shift would lead him to publish the final version of his accident model, based on the Swiss cheese metaphor.

A comparison of the different graphical explorations he produced during the 1990s raises several interesting issues. First, the graphical choices probably follow, and might be evidence of, Reason's progressive immersion in the industrial world, notably given the relationship between his consulting activities and his published books and articles. It is likely that he sought to adapt his models in ways that reflected his evolving views. His immersion was a result of both his research

[9] As this model was not named, we refer to it as Mark X.

[10] This informs the discussion in Section 4.1.

[11] Unlike *Human Error* (1990), which was written for scholars (professors, students, researchers).

[12] Air Traffic Controllers.

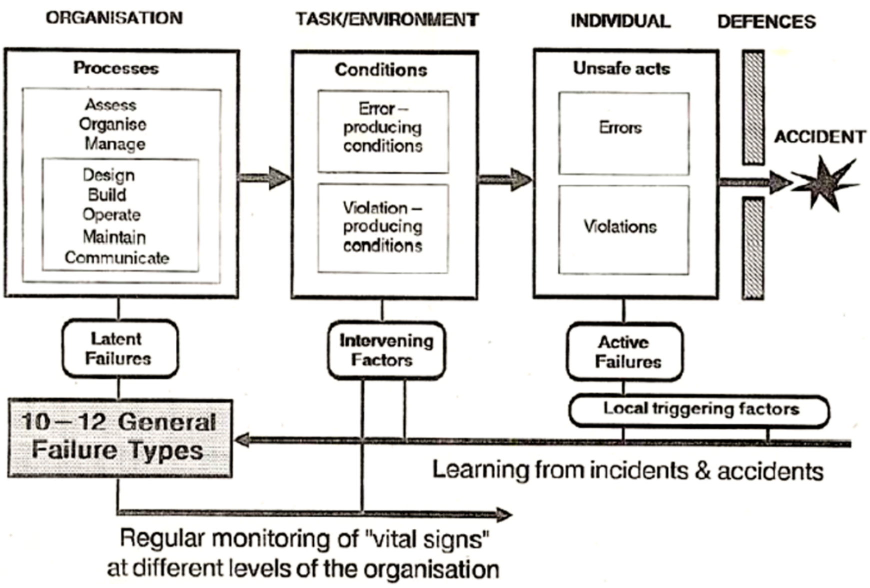

Fig. 4. Mk II referring to the General Failure Types found in TRIPOD (Reason et al., 1989).

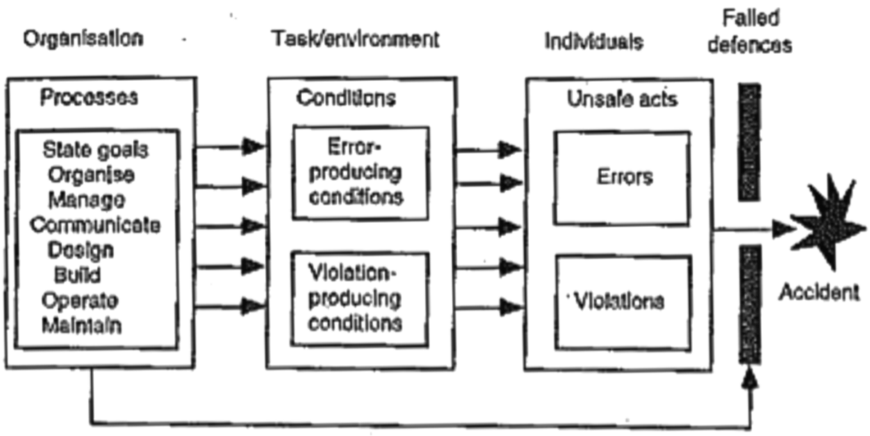

Fig. 5. Alternative version of Mk II (Reason, 1993).

(conferences, accident investigation) and commercial activities (consulting, programs financed by industry). Second, despite marginal adjustments and profound changes in the structure and lexicon, none of these variants had the same impact as the SCM in terms of citations or influence on practices. Third, the same idea (an accident occurs when the system's defences fail) is represented by fundamentally-different graphical choices (see Table 1).

We examine the evolution seen in these graphical and labelling choices amongst the different versions of Reason's OAM from the point of view of its main critics (Section 4). Indeed, when a model is based on a graphical product presenting the articulation of concepts, one must admit that graphical modifications may alter the way the theory is perceived and received.

3.2. Summary: Why was the SCM so successful?

What conclusions can we draw from this study of the SCM's genesis? The first point to note is the transfer of metaphors across domains, and the importance of the social contexts that fostered this transfer. The previous section shows this idea particularly well: the metaphors of resident pathogens (from the medical domain), defence in depth (from engineering) and Swiss cheese (food) are combined to produce the most-popular safety model (Underwood and Waterson, 2013). The model makes complex ideas easily understandable and, thus, has significantly contributed to promoting the organisational accident paradigm in many sectors of activity. Several 'eureka' moments can be identified when the three minds came together, each being a stepping stone to the final result.

But these metaphors would be nothing without the graphical aspect. This is second consideration to keep in mind when contemplating the success of SCM: namely the importance of diagrams and visualisations in general and in the safety field (for a list of visual properties, see Le Coze, 2013, 2019b, 2018). A key attribute of drawings and diagrams is that they are based on a different logic compared to text. While texts are sequential and linear, diagrams and drawings are not (Kress, 2003). They exploit the potential of spatial configurations to produce a whole this can be easily grasped. As the expression says, *a picture is worth a thousand words*. The relationship between ideas, text and diagrams is particularly complex. What comes first: words, diagrams and drawings or ideas?

It seems that in this respect, Reason had a powerful drawing, but not necessarily the text to go with it, hence his subsequent attempts to

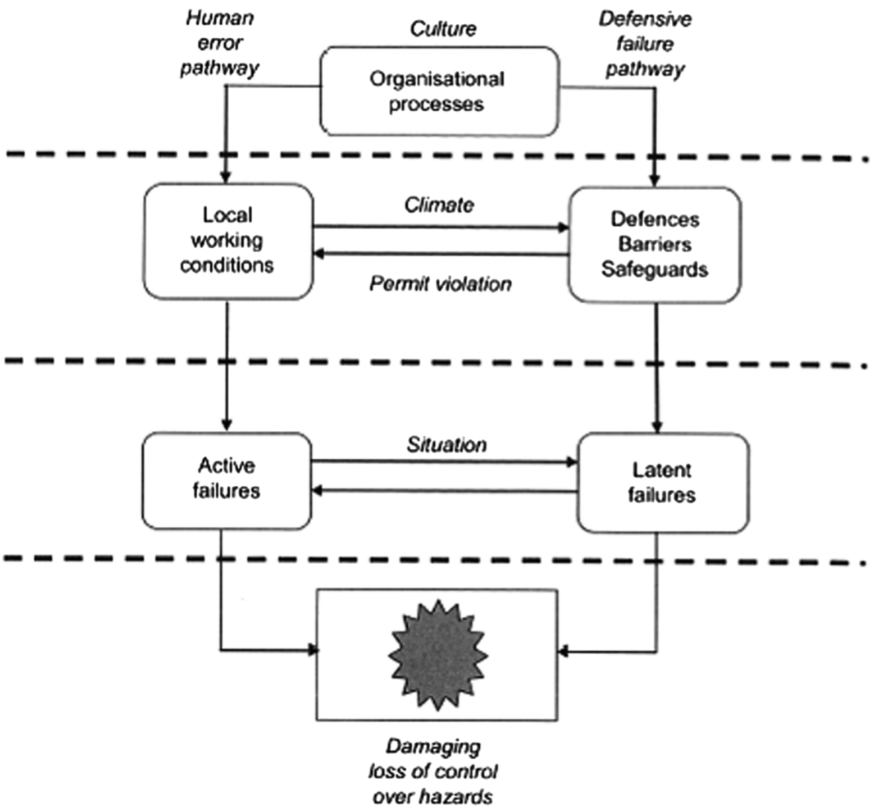

Fig. 6. Mk X and its original vertical representation (Maurino, et al., 1995).

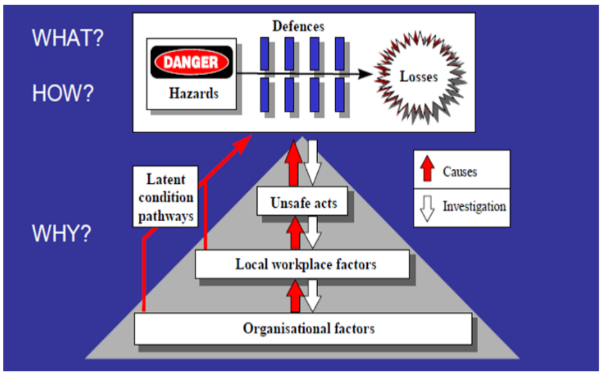

Fig. 7. Mk III combining a vertical and horizontal reading (Reason, 1997).

Table 1
Different representations of the OAM.

Version (year)	Representation	Reading direction
Mk I (1990)	Perspective	Left to right
Mk II (1990)	Flat	Left to right
Mk X (1995)	Flat	Top to bottom
Mk III (1997)	Flat	Left to right & top to bottom
SCM (2000)	Perspective	Right to left

refine and to develop the drawing (Table 1). The drawing preceded words. It captured something that words could not grasp. But that is not all. Drawings have been described as *boundary objects*, in the sense that they help different actors with different backgrounds to coordinate their actions (Stars, 2010). Because they are loosely defined, they allow a multiplicity of interpretations while, at the same time, supporting or channelling a view that can be shared by different stakeholders. This *interpretive flexibility* of a boundary object applies particularly well to the SCM, and we will explore the question in greater depth when discussing its critiques.

The third consideration is related to the second, and concerns the interplay between research and consulting. Reason refined his model at a time when he was working with the industry (see Figs. 2–7), and the initial design was a result of his interactions with a consultant, John Wreathall. It seems more appropriate to talk about Reason's *models* more than *the* Reason model (Larouzée and Guarnieri, 2014). This proximity with real-life problem-solving in operational contexts is important in a field such as safety. How do research and practice interact? How can useful models be generated? To what extent is safety research useful in practice? The genesis of the SCM illustrates a specific set of circumstances when two worlds fruitfully interacted – with the help of, among other things, diagrams and drawings.

Of course, Reason's taxonomic approach to error, and his analysis of accidents were supported by texts to a great extent, but his visualisations played a key role. The abundance of diagrams in Reason's work is not exclusive to safety research; it is also found in the field of management, for instance, because of its close ties with business and practitioners. An example is Mintzberg, whose work was also very much drawing oriented (e.g. Mintzberg et al., 2009). The practical side of safety research is illustrated by Reason's models. As the results of his work must make sense to practitioners, drawings and diagrams are a great help in visualising his ideas (although his work should not be reduced to this aspect, as drawing consists in conceptualising, and not only communicating).

Finally, a fourth consideration is the complex topic of how to establish satisfactory micro/ macro links. Like Rasmussen, Reason's approach shifted from the cognitive to the systemic, while both authors trained as cognitive psychologists. How can we bridge the gap between the two? For Rasmussen, the idea of degrees of freedom, coupled with the notion of self-organisation (from cybernetics) was a solution. He drew upon his naturalistic approach to cognition, which led to the conclusion that individuals were highly adaptive. They could always finding a way to cope with circumstances, often very positively but, sometimes, with negative consequences (Le Coze, 2015a).

For Reason, bridging the micro/ macro gap was difficult to apprehend from an analytical point of view, while for Rasmussen, it triggered useful metaphors such as drift (Snook, 2000; Dekker, 2011) and resonance (Hollnagel, 2004). A full discussion of the micro/ macro issue is beyond the scope of this article, but the point will be addressed again when exploring the relationship between the text and drawings (in Reason's case) and, second, when considering his critics (in particular Hollnagel's classification).

4. Critiques and critics of the SCM

Three years before the initial publication of the SCM, Reason noted, "*the pendulum may have swung too far in our present attempts to track down possible errors and accident contributions that are widely separated in both time and place from the events themselves*" (Reason, 1997; p. 234). This can be considered as the first ever critique of his OAM, "*ironically, it seems that the only person to question the use of Reason's Swiss cheese model is Reason himself!*" (Shorrock et al., 2005). The heuristic power of the SCM, one of the factors of its widespread popularity, also seems to have led to its dogmatic use, "*It may be the case now that industries and organisations have latched on to the model in a far too rigid and dogmatic fashion. As a consequence, investigations based on the Reason model can easily turn into a desperate witch-hunt for the latent offenders when, in some cases, the main contributory factors might well have been 'human error' in the traditional sense.*" (Young et al., 2004).

Ten years after the publication of the first OAM, the 2000s marked a period when Reason's work was subject to increasing criticism. It should be noted that these criticisms relate exclusively (to the best of our knowledge) to the SCM as it was presented in the BMJ article, and neglect the epistemological and methodological insights provided by other versions (as discussed in Section 3). We divide this criticism into two categories: (1) challenges related to the representation of the accident (Leveson, 2004, 2011, 2012; Leveson and Thomas, 2013; Dekker, 2006; Qureshi 2007; Hollnagel, 2004, 2012); and (2) authors who consider the model to be too generic and underspecified (Shappell and Wiegmann, 2000; Luxhøj and Maurino, 2001; Dekker, 2002; Luxhøj and Kauffeld, 2003; Arminen et al., 2010; Fukuoka, 2016). Second, we develop a 'critique of the criticism', based on a detailed study of the SCM's genesis (presented in Section 2), and its early versions, their graphical representations and their relationship to practice (presented in Section 3).

4.1. The SCM: static, linear and too simplistic?

Perhaps the most popular analysis and critique of Reason's SCM is Hollnagel's view of the model as an 'epidemiologic' or 'complex linear' version of accident models. Hollnagel (2004) distinguishes between: (1) simple linear models that attribute the accident to the ordered interaction of a series of events over time, and which direct prevention efforts towards the elimination of the causes of this linear sequence; (2) complex linear (or *epidemiological*) models that attribute an accident to the linear combination of latent conditions and risky acts, thereby shifting the analysis from the individual to the organisation and its management, but still guiding prevention towards strengthening system defences; and (3) systemic models. The latter represent the latest evolution in modelling and are characterised by a dynamic view of accidents in which causes and effects interact. Dekker concurs, stating that a static view of the organisation fosters the idea of linear accident causality. He argues that presuppositions such as a decomposable system, independent subsystems and linearity of causes may lead safety practitioners to seek to ensure the quality of components or subsystems, while failing to consider the system as a whole (Dekker, 2006).

Leveson goes one step further, and describes the SCM as an obsolete descendant of Heinrich's *domino model* from the early 1930s. "[The] *Swiss cheese model is simply another version of Heinrich's Domino Model with different terminology (slices of cheese rather than dominos) and the idea of barriers or defenses from the process industry. Note that independence of the barriers is assumed and some randomness in whether the "holes" line up. Also, as in the Domino Model, a human (operator) "unsafe act" is seen as the final event while ignoring other types of "active failures" at the time of the accident. Finally, the underlying causes of the events are ignored other than a lack of barriers to prevent their propagation.*" (Leveson, 2011). The natural conclusion of these established safety researchers is that "the *Reason's Swiss cheese is no longer adapted to anticipate today's accidents.*" (Leveson, 2004). This type of classification is still used in many literature reviews (e.g. Qureshi, 2007; Toft et al., 2012). Authors who refer to it either classify it as part of the family of simple or complex linear models and consider it as non-systemic, are claim that it over-simplifies the aetiology of accidents.

4.2. The SCM: Underspecified and overly generic?

The second criticism of the SCM argues that it is too generic. Such criticisms go beyond a representation "bias", recognising its complexity and even its systemic nature. However, they claim that its graphical simplicity does not provide any understanding of the links between different causal, organisational, local and individual factors (Luxhøj and Maurino, 2001; Dekker, 2002). For others, the lack of specificity is a weakness. In particular, users lack of guidance, since the representation provides no tools to transpose the metaphor of slices and holes to real situations (Shappell and Wiegmann, 2000; Arminen et al., 2010). Practitioners must make their own interpretation and adaptations, with the risk that the model has little utility in real-life (Luxhøj and Kauffeld, 2003). Although these critiques recognise the SCM's contribution to the field of safety sciences, they point out that its graphical simplicity limits its usefulness in practice.

4.3. A critique of the criticism

An in-depth study of Reason's work offers a different perspective on the criticism presented above. Our view is, however, consistent with Reason's own interpretation of his critics. First, we reaffirm Reason's own view of the model, "*from an academic perspective the weakness of the SCM is that it is irrefutable by standard scientific methods – a distinction it shares with many other models from Freud's to Endsley's. There is no 'crucial experiment' that can be used to reject the model. But then it was never intended to be a scientific model on that level.*" (Reason et al., 2006). However, as shown above, the value of his models, in particular the SCM, is the ability to create a powerful visual heuristic that a diversity of people can share. It offers a representation that different professionals, with different levels of expertise in safety critical organisations (including regulators), can understand.

Perneger (2005) investigated the extent to which health professionals who regularly used the SCM understood its basic elements. The study took the form of a questionnaire that presented the SCM with no accompanying text. A series of multiple-choice questions focused on the meaning of the different elements (slices, holes and arrows). Although respondents correctly interpreted the slice as a protection barrier, and the hole as a failure, only a few understood that they represented both a latent condition and an unsafe act.

Furthermore, only half correctly interpreted the arrow as a path leading to the risk of an accident (the other half considered that the arrow led to an error). Only 30% identified an active error as one of the holes. Finally, while the majority considered that "*fixing a hole*" improved the safety of the system, few selected the solution "*add a* *barrier*". Perneger notes that only respondents who were 'at ease' or 'very comfortable' with the model were selected, and highlights that, "*invoking the Swiss cheese model will not necessarily lead to effective communication, even among quality and safety professionals.* […] *The danger is that people today use the label 'Swiss cheese model' without realising that its meaning varies from one person to the next*" (*op. cit.*).

The latter study suggests that while the intuitive understanding and interpretive flexibility of the SCM is precisely what has made it so successful it is also, for some, a fundamental drawback. Although not everyone will agree with this statement, different interpretations are to be expected. This raises an interesting empirical question: how does the SCM help to represent reality, despite diverging understandings and use? The answer to this question provides an initial response to the model's critics: the heuristic, collaborative and performative aspects of the SCM, which are at the heart of its success, should not be neglected.

The model has managed to strike a balance between generic, intuitive, normative and underspecified content (Le Coze, 2013, 2018, 2019b). We could lament that it does not provide users with clearer guidance but, "*le simple est toujours faux. Ce qui ne l'est pas est inutilisable*"[13] (Valéry, 1960). Nevertheless, the SCM has significantly contributed to shifting the focus of accident prevention from the individual to a broader, systemic view. This brings us to another criticism from safety scholars.

A key criticism, from a more analytical point of view, is the linear causality implied by the arrow through the holes, which Hollnagel (2004) argues makes it 'complex linear' or 'epidemiological'. We believe that this classification is motivated by Rasmussen's framing of the micro/macro link based on a self-adaptive view of the problem.[14] Indeed, as noted above, Reason's metaphor of pathogenic agents suggests a loose connection, while the principle of self-adaptive behaviours that combine into emergent (non-linear, due to circular causalities) complex patterns is a more explicit approach (we explore the distinction in Fig. 8). At the same time, the SCM is systemic in the sense that it looks at the system as a whole, and explicitly includes senior decision-makers, rather than taking a reductionist approach that is limited to frontline actors.

The difference appears not to be between systemic or non-systemic approaches, but rather between the underlying metaphors that structure the principles of our understanding of accidents as systemic events. One could even argue that Reason's view is more systemic because it offers a better visual representation of the impact of senior actors than Rasmussen's migration models, or later work by Hollnagel et al. (2006). Rather than seeing models from an evolutionary point of view, it might be better to nuance our perspective, by describing their strengths and weaknesses as a function of many different dimensions (e.g. Le Coze, 2013), without implying, as other do, that more complex models are more relevant than linear models (e.g. Hollnagel, 2004). We therefore agree with Reason's own argument that, "*'Swiss cheese' is primarily about how unsafe acts and latent conditions combine to breach the barriers and safeguards.* […] *I still think of it as a systemic model* […] *Just as there are no agreed definitions and taxonomies of error so there is no single 'right' view of accidents. In our business, the 'truth' is mostly unknowable and takes many forms. In any case, it is less important than practical utility*" (Reason, 2008; pp. 94–95).

4.4. A critique of the critics

In this section, we go further and look at the critics themselves, drawing upon insights from both research and consulting. A detailed analysis of the critics of the SCM must go beyond *what* is said, to try to understand *why* it was said. For example, Leveson et al.'s (2011) declaration that, "[in Reason's model] *as in the Domino Model, a human (operator) 'unsafe act' is seen as the final event while ignoring other types of 'active failures' at the time of the accident*" (our underlining) contains a misinterpretation. In this statement, an "unsafe act" is considered to be the final event (i.e. at the end of the SCM's arrow) while, as we have shown (in Section 2.2), the final event is, in fact, the accident. The critics' error is therefore to substitute one of the causes for the consequence. This statement also makes the arguable claim that the SCM and the Domino model are equivalent. While it is clear that visually, they look similar; their historical and conceptual backgrounds are quite different. We therefore believe that it is important to understand the SCM's critics from two (complementary) angles: *scientific* and *commercial*.[15]

The first aspect can indicate a process of institutionalisation within the safety sciences research field. Indeed, if the SCM is considered as a central model that one needs to critique, it's because it follows the idea promoted by Kuhn (1962), among other, that science evolves in stages. Our worldview is revolutionised as models adapt to new problems that previous models could not incorporate. Because of a stated increase of complexity of sociotechnical systems, old safety models would not be adapted anymore, hence the need to transform them. Interestingly, such critiques also show the increasing maturity of the safety research field, as models are criticised, discussed and debated in order to produce new ones. Reputations are made by promoting alternative views and challenging the contribution of established authors.

The second aspect is commercial. In addition to selling books and attending conferences (Reason presented his ideas at more than 280 conferences; Reason et al., 2006) Reason and Wreathall founded Wreathall & Co. in the early 1990s. This company (co-directed by Reason) undertook numerous commercial projects for major industrial groups such as British Airways, British Petroleum, and the Nuclear Regulatory Commission in the United States. They worked together, with Wreathall developing business contacts and Reason conceptualising and publishing the outcomes of their consultancy work.

The link between their commercial and research activities is illustrated by the Management Engineering Safety and Health (MESH) method developed by Wreathall & Co. for British Airways Engineering (Reason, 1995). Reason would remain a part-time employee of the company (which became the WreathWood Group) until his retirement in 2012. From this perspective, the SCM can be considered a product that created —and conquered— a market. This makes it a target for commercial strategies that seek to replace it with new alternatives (other models, or audit and analysis methods). The 1980s and 1990s saw the explosion of consulting in many areas (Kipping and Clark, 2012), and safety was no exception, providing many business opportunities for experts and consultants in the field (Le Coze, 2019c). The SCM was one of the first models to provide its creators, and many other consultants, with a way to earn a living.

Although it is difficult to clearly distinguish between criticism based on scientific and commercial motives, such ambiguities are inherent in the nature of safety research.

5. Conclusion

In this article, we reviewed the genesis (Sections 2.1 and 2.2) and the evolution (Sections 3.1 and 3.2) of Reason's organisational accident models. The SCM, in particular, owes its success to a systemic foundation that broadens the scope of the analysis to the organisation's complexity, environment, management and defences. These foundations emerged from fruitful, complementary and ongoing exchanges between disciplines (e.g. engineering sciences and psychology), fields (e.g. academic and industrial) and people (e.g. James Reason, John

[13] "What is simple is always wrong. What is not is unusable".

[14] It should also be noted that these criticisms only relate to the SCM, and not Reason's other models.

[15] Busch reaches a similar conclusion in his study of how Heinrich has recently been depicted by some safety writers (Busch, 2019).

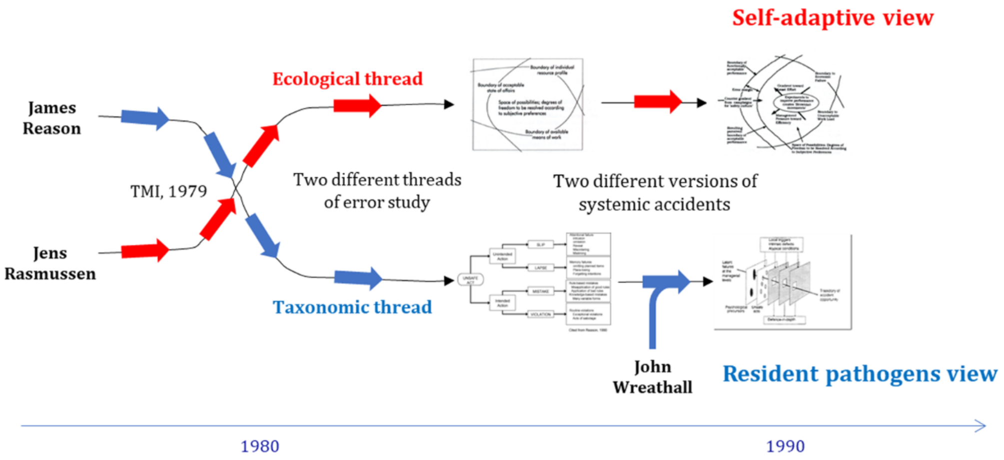

Fig. 8. Two epistemological threads leading to two versions of systemic accident models (based on Le Coze, 2015a).

Wreathall, Rob Lee and Patrick Hudson). The model draws upon a general, easy-to-remember and adaptable graphical representation that makes it easy to visualise (and conceptualise) the notion of the organisational accident. By the 2000s, its success had led, naturally, to a debate on its proposed vision of the accident (Section 4.1) and its ability to guide practice (Section 4.2). We proposed some motivations for this criticism, notably distinguishing between scientific and commercial drivers (4.3). We conclude this historical and critical review of the SCM by reaffirming the strengths of the model and defending its ongoing relevance. The debate on whether it is linear or systemic must be put to one side, and its contemporary character should be understood in terms of its influence on practice (Underwood, 2013) without neglecting its analytical limitations (Le Coze, 2013).

Reason concluded his work by noting that he had attempted to "*reconcile three different approaches to safety management: the person model […] the engineering model […] and the organisational model*", pointing out the "*predominance of the person model in situations that demand a closer consideration of technical and systemic factors*" (Reason, 1997). His observations, indicated the need for an additional, practical and sociological reading of accidents, an example of which has been provided in the meantime by Hopkins (Le Coze, 2019a). Safety science researchers and practitioners need to keep engaging in such empirical, multilevel and ethnographic studies, coupled with theoretical work that combines empirical, practical and graphical approaches. When doing so, they pursue the systemic ambition of the SCM, in the spirit of Reason's legacy

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