From theory to practice: itinerary of Reasons' Swiss Cheese Model

Justin Larouzée, Franck Guarnieri

From theory to practice: itinerary of Reasons' Swiss Cheese Model

J. Larouzée & F. Guarnieri
Centre of Research on Risks and Crises (MINES Paristech), Sophia-Antipolis, France

ABSTRACT: Since the early 1990s, the Swiss Cheese Model (SCM) of the English psychologist James Reason has established itself as a reference model in the etiology, investigation or prevention of organizational accidents in many productive systems (transportation, energy, healthcare …). Based on the observation that it's still today widely used, this article intends to revert to the history and the theoretical background of the SCM. By doing so, the article focuses on the collaboration between the psychologist (James Reason) and a nuclear engineer (John Wreathall) who happened to be at the origin of the creation and evolution of SCM. The methodology is based on an exhaustive literature review of Reason's work and the interviews of Reason and Wreathall carried out in 2014. The study suggests that the success of the model is not so much due to appropriation of the work of the psychologist by the industrial community but to a complex process of co-production of knowledge and theories. To conclude, we try to figure out whether the SCM still has a contemporary interest in accident prevention or explanation.

1 INTRODUCTION

Since the early 1990, the *Swiss cheese* Model (SCM) of the psychologist James Reason has established itself as a reference model in the etiology, investigation or prevention of industrial accidents. Its success in many areas (see table 1) has made it the vector of a new paradigm of *Safety Science*: the organizational accident.

Table 1. Non exhaustive list of sectors applying Reason's work (Larouzée et al., 2014).

Sector	Bibliographical reference
Aviation	- Maurino (1993) - Shappell (2000)
Marine	- Ren et al. (2008)
Healthcare	- Vincent et al. (1998) - Carthey et al. (2001) - Lederman & Parkes (2005)
Defense	- Jennings (2008)
Nuclear	- Reason et al. (2006)
Oil & Gas	- Hudson et al. (1994)
Rails	- Reason et al. (2006) - Baysari et al. (2008)
Roads	- Salmon et al. (2005)

Based on the observation of its wide use and quotation rate (25000 citations according to Google Scholar), one can wonder (1) why is this model more than any others still at the agendas of the industrial community and (2) Is this model, conceptualized in the 1980s, still able to explain the accidents in 2015? This contribution is therefore trying to question the contemporary character of Reason's model.

Most of this work, conducted during the year 2013, is based on an exhaustive literature review of Reason's published work (N = 135 publications; Larouzée & Guarnieri, 2015). This literature review includes articles, books and book chapters, conferences and industrial reports. It has been completed by the interview of Professor James Reason in January 2014 and John Wreathall in October 2014. Thanks to the use of both published work and interviews to study the history and genesis of the SCM, we tried to keep from retrospective bias (that tends to smooth and simplify facts).

The section 2 of the paper is dedicated to the history of the SCM. First, we briefly present James Reason's academic background through his main topics of interest (2.1) and John Wreathall (2.2). Second, we focus on the social and historical context in which the two fathers of the SCM met and were able to collaborate (2.3). In the section 3, we focus more specifically on the shift of Reason from *theoretical* to *applied* work on human error. This change is argued to be due to collaboration between the psychologist and the nuclear world (3.1). Becoming familiar with the industry and collaborating with Wreathall gave Reason the opportunity to attach his theory to an empirical and functional view of organizations (3.2). Reason's work also benefits of the defense-in-depth theory inherited from nuclear safety (3.3). The section 3 finally considers the effects of a long lasting collaboration between the psychologist and the engineer that gave the model opportunity to evolve (3.4).

2 HISTORY OF A MODEL

This section presents the two fathers of the SCM. Reason a psychologist of human error and Wreathall a nuclear engineer. After presenting their backgrounds (subsection 1 and 2), we present the social and industrial context in which they were brought to meet and work to create the first version of the SCM (subsection 3).

2.1 *James Reason, psychologist*

Reason gets a degree in psychology at Manchester University in 1962. He then works on aircraft cockpit ergonomics for the (UK) Royal Air Force and the US Navy before defending a thesis on motion sickness at Leicester University in 1967. Until 1976, he works on sensory disorientation and motion sickness. In 1977 he becomes professor of psychology at Manchester University. In 1977, Reason makes a little action slip that will impact his scientific career. While preparing tea, he began to feed his cat (screaming with hunger). The psychologist confused the bowl and teapot. This was of great interest to him and he started a daily errors diary. With applied cognitive psychology methodologies, he began his research on human error. Reason defines *human 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) from there, he differentiates between the miss-application of a well planned action (*slips* and *lapses*) and the good application of a miss-planned action (*mistakes*). After ten years working on the topic of everyday errors, Reason ended with a taxonomy of unsafe acts (1987).

After he became a referent on the issue, he has been a keynote speaker in various international conferences on human error. During these conferences, he met John Wreathall, nuclear engineer, with whom Reason built working relationship and "*strong intellectual communion*" (in his words). On their collaboration will be drawn the first version of the SCM. After publishing the first version of the model in the book Human Error (Reason, 1990), Reason kept working on human and organizational factors in practical ways, applied to many industrial fields, for the next ten years. In 2000, he started working on human error prevention in the British healthcare system. In 2003 thanks to the efficiency of his work, he was appointed *Commander* of the *British* Empire.

Most of the users of the SCM including the safety science researchers do only know the post-SCM James Reason. This very short biography (see Larouzée *et al.*, 2014 for an extended one) shows his trajectory from laboratory experiments on motion sickness to a comprehensive and innovative view on organizational accidents (table 2).

Table 2. James Reason's main research topics.

Topic	Period	Main publication
Motion Sickness and disorientation	1967-1981	Motion Sickness (1975)
Everyday errors, inattention	1977-1987	Absent-Minded? (1982)
Error taxonomy	1987-1990	Human Error (1990)
Organizational accidents, Safety culture, Violations	1990-2000	Managing the risk of organizational accidents (1997)
Applied work for healthcare system	2000-2013	Human error : model and management (2000)

2.2 *John Wreathall, the engineer*

John Wreathall studies nuclear engineering at London University, undergraduate in 1969; he gets a masters' degree in systems engineering in 1971. Later he studies an Open University course "*Systems Thinking, Systems Practice*" based on Pete Checkland's models of systems. This option brings the young engineer to human factors and systems thinking. From 1972 to 1974 he works on the British nuclear submarine design which allows him to access confidential reports on HRA by Swain. From 1976 to 1981, Wreathall works for the CEGB (English Electric Company), first as design reviewer for control systems then as an engineer on human factors in nuclear safety. As an acknowledged expert he was brought to participate in conferences organized by NATO and the World Bank called Human Error (book "*Human Error*" by Senders & Moray is the only published product from the 1981 conference of the same name). After meeting Reason there, they both started professional collaborations on accident prevention models (including SCM). His interest in the human factor brought him to several leading functions where he worked on human factor. Most of his works also were funded by the nuclear industries in the USA, Japan, Sweden, the UK and Taiwan, and by the US Nuclear Regulatory Commission.

2.3 *Meeting and collaboration, a particular context*

Industrial and research community's interest for human factors is nothing new in the mid-1980s. By the 1960s, development of the nuclear industry and modernization of air transport stimulates many research programs (e.g. Swain, 1963; Newell, Simon, 1972; Rasmussen, 1983; quoted by Reason, 1990). Researches then were mostly conducted under the 'human error' paradigm. The 1980s were marked by a series of industrial accidents (Three Mile Island, 1979; Bhopal, 1984, Chernobyl and Challenger, 1986; Herald of Free Enterprise and King's Cross Station 1987; Piper Alpha, 1988). Investigations following these accidents brought the Safety community to question the understanding of accidents solely based on operator error. In this scientific, industrial and social context, NATO and the World Bank funded many multidisciplinary workshops on accidents. The first one was held in Bellagio, Italy, 1981. It received the name of "first human error clambake".

At Bellagio's Clambake, Reason and Wreathall met. This fortuitous meeting led them to become (in Wreathall words) "*social friends*". Indeed, according to Wreathall, "*intellectual communion was quick with Reason but also with other researchers in vogue on the issues of human error at the time. Swain, Moray, Norman*". Reason and Wreathall started corresponding and met at different conferences during the 1980s. Both took commercial projects for industrial groups such as British Airways and US NRC in which they employed each other as professional colleagues. At that time Reason was ending his taxonomy of unsafe acts. He started writing a book on human error aimed to his cognitive psychologist peers. The Safety Culture Decade context and choice of reducing first chapter's size brought him into writing a chapter on industrial accidents. Therefore, he intended his book to both the research and the industrial world (he progressively became familiar with thanks to his Wreathall & Co's joint missions as well as others). To communicate his new vision of organizational accidents, Reason called on his friend Wreathall to help to design a simple but effective model that would be included in the 7th chapter of Human Error. This model was to become, ten years later, the famous SCM.

3 THEORETICAL MODEL FOR PRACTICAL USES

The second section has presented the two SCM's fathers, their backgrounds and the context in which they were brought to meet. This section focuses on their collaboration from 1987 (when the writing of Human Error begun) to 2000 (publication of the latest SCM version). We first look back at the discovery and exploitation by Reason of the nuclear field (3.1). We then explicit the shift that the psychologist made from fundamental to applied research (3.2). The next part of the section is devoted to the percolation of defense in depth into the SCM (3.3). Finally, we look at the developments which led the Wreathall and Reason's early accident model, to become, in 2000 the famous and widely used SCM (4.4).

3.1 *Meeting the nuclear world*

In the late 1970s Reason is still far from the nuclear power plant (NPP) control rooms. Yet this industrial field will be one of the most influential for his work. In 1979, the TMI incident operates an awareness of the influence of local workplace conditions on the operator's performance. If Charles Perrow sees in TMI the advent of a *normal accident*, Reason finds the first level of his taxonomy: distinction between *active* and *latent* errors[1]. In 1985, Reason and Embrey publishes an article dedicated to human factors in abnormal conditions of NPPs (Reason & Embrey, 1985). One year later, the Chernobyl disaster provides an unfortunate case study. Reason introduces a new distinction between errors and violations in his taxonomy. In 1987, he publishes an article in *British Psychological Society* bulletin devoted to Chernobyl errors' study from a theoretical perspective. In 1988, he publishes *modeling the basic tendencies of human operator error*, thus introducing an error model which allows modeling the human behaviour of problem solving (the Generic Error Modeling System, GEMS). Reason's cognitive models were then based on observations in NPPs control rooms as case study of human behavior.

The development of distinction between accidents theories based on active or latent errors and violations, is strongly linked to the development of nuclear energy and its safety culture. From 1979 to 1988, Reason uses accident investigations and gets used to the field and its culture. For all that, his productions remains designed to his peers. A turning point is met when the observation process becomes a collaborative one and that Reason's psychologist work mingles with the engineering one of Wreathall.

3.2 *From theory to practice*

1987 represents a break in Reason's work (Larouzée et al., 2014). After studying everyday errors for ten years, Reason holds a major contribution to his discipline with the taxonomy of unsafe acts (Reason, 1990, p. 207). He publishes the *Generic Error Modelling System (*Reason, 1987; Fig. 1), a combination of his classification with the *Skill, Rule, Knowledge* (SRK) model of Danish psychologist Rasmussen (1983). It presents the types of human failures linked with the specificities of a given activity. This theoretical cognitive model still belongs to the field of psychological research (model quoted 192 times).

The same year, Reason works on a chapter of *Human Error* dedicated to industrial accidents and designed for security practitioners. He has the backing of his friend Wreathall. Reason says he looked for a manner of "*showing people what our work was about*". Wreathall talks in these terms of the genesis of the first model "*during an exchange in a pub the Ram's Head in Reason's home town* (Disley Cheshire, England), *we have drawn the very first SCM on paper napkin. Initially, James saw the organizational accident as a series of "sash" windows opening or closing thus creating accident opportunity*". Wreathall literally allowed the psychologist combining his accident theory (resident pathogens metaphor; Reason, 1988) and his error taxonomy with a pragmatic model of any productive system.

---

[1] Where *active errors,* often committed by the front-line operators, have almost immediate effects and *latent errors*, committed by actors whose activities are removed in time and space form the direct control interface, have adverse consequences likely to remain dormant within the system for a long time (only becoming evident when they combine with other factors to breach the system's defenses). (See Reason, 1990; p. 173).

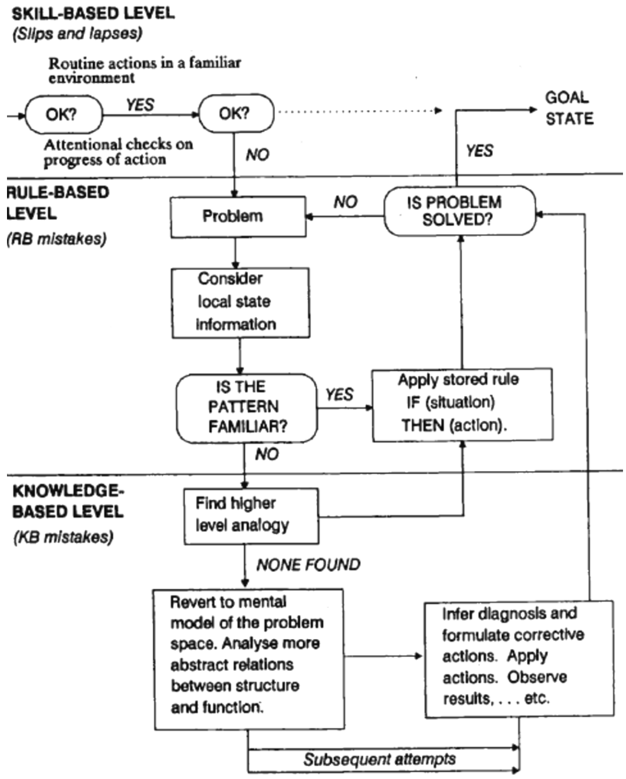

Figure 1. Reason's taxonomy backed at the cognitive SRK model of Jens Rasmussen produces a theoretical cognitive model.

The shift over, the cognitive and theoretical model changed into a descriptive and empirical one (Fig. 2). The book Human Error received a warm welcome by both research and industrial communities (quoted 8604 times). Reason became a Wreathall & Co' director and continued his work related to industries "*he supported psychological dimensions of the reports produced by the firm.* As early as 1991 according to Wreathall*, James was familiar with the engineering community and became conductor of the various works made by Wreathall & Co', especially for the American nuclear domain*". Reason will remain a part-time collaborator of Wreathall & Co' and then *WreathWood* Group until he retired in 2012.

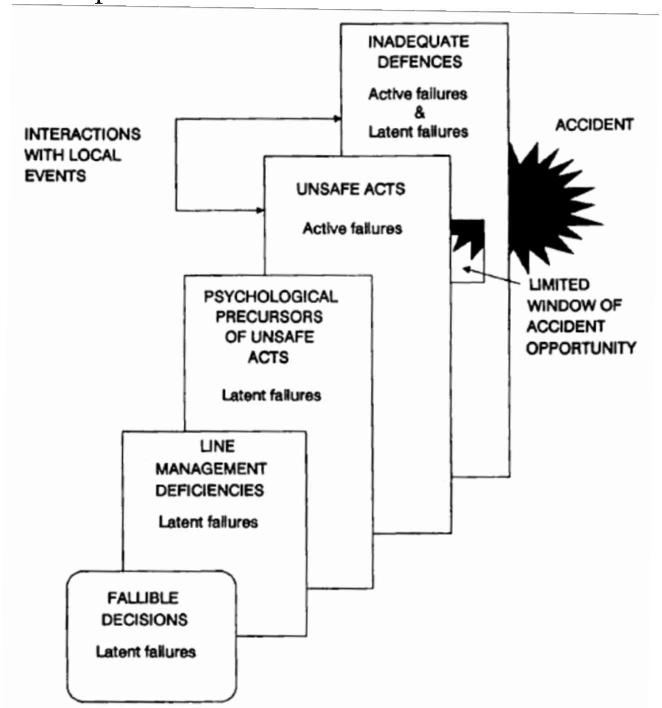

Figure 2. Reason's taxonomy backed at the productive system model, drawn by Wreathall, produces an effective descriptive and empirical model.

3.3 *The defense in depth contributions*

The engineer's contribution goes beyond the pragmatic modeling of a productive system. Wreathall's training and experiences with the British submarines nuclear reactor and CEGB NPPs safety gave him specific defense in depth[2] thinking. When he designed the first SCM, Wreathall chose a representation of superimposed plates. These plates evokes defense in depth's *levels of protection*. Reason then explains each plate's failure using his taxonomy and understanding of organizational accidents. The *Swiss cheese* nickname and representation is late. Still it's rooted in the first graphical choice. Wreathall's contribution overtakes engineering understanding of a system: it carries the defense in depth thinking.

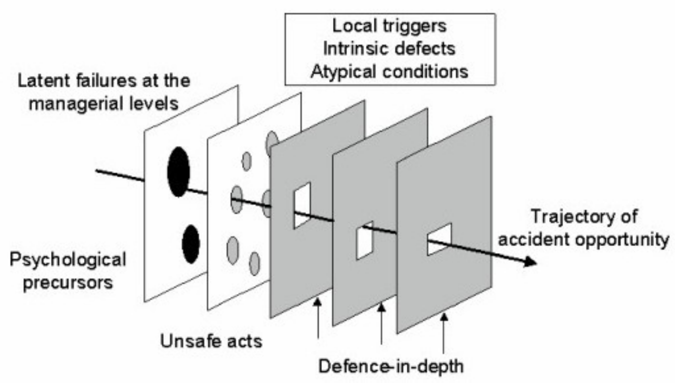

Figure 3. This version of Reason's accident causation model (published in Human Error, 1990) explicitly introduced the "defense in depth" concept as a label.

Defense in depth is clearly mentioned in an early SCM version (Reason, 1990, p.208; Fig. 3)[3]. It incorporates an accidental *trajectory of accident opportunity* which provides information on respective contributions of the psychologist and the engineer. On the left hand side, the white plates represent the organizational (managerial level) and human failures (unsafe acts): contribution of the psychologist. On the right hand side, gray plates represent defense in depth as a block (set of defenses ensuring the system's integrity): it's the engineer contribution.

Human variability may confuse the engineers (this partly explains the historical *human error* understanding of accidents). On the other hand, technical and organizational sides of safety often confuse academic researchers. In the SCM case, the collaboration of two disciplines (engineering science and psychology) has the effect of two eyes in binocular vision: close an eye and you lose the perception of reliefs. Collaboration gave to Reason and Wreathall insights on the complex interactions between humans and technology and therefore, emergent properties of system's security. In a way, Reason's work as a whole proposes an early systemic vision of the accident, considering retroaction (feedback loops) and interactive effects.

The SCM is sometimes considered as a linear causal model (surprisingly often by researchers who come out with their own non-linear, non-causal models). Reviewing the published critics of the SCM, we haven't find so far arguments based on something that would not be the simple, empirical, representation of the organizational accident theory (Fig 4.). If there are differences in graphical complexity between theoretical and empirical models that are to be noted the epistemological posture of a theory cannot be determinate only on its graphic representation.

---

[2] Early 1960, the military *defense in depth* concept is introduced into the US nuclear safety policies. It concerns the hardware and construction design (fuel and reactor independent physical barriers containment). The TMI incident extends it to human and organizational dimensions. In 1988, an International Atomic Energy Agency working group publishes an issue entitled *Defense in depth in nuclear safety* (INSAG, 1988) which establishes defense in depth as a doctrine of nuclear safety. Doctrine based on three concepts: *barriers* (implementation of physical protection systems), *defensive lines* (structural resources and organizational security), and *levels of protection* (arrangement of barriers and defensive lines according to structured objective regarding the potential event's gravity).

[3] If the original version labels *defense in depth* (Fig. 2.), the 1993 French translation (by an academic) changes the label for « *défenses en série* » (literally *serial defenses*). Loss of sense due to field sensitivities' manifestation.

3.4 *A long term collaboration*

Reason and Wreathall kept working together and using the SCM within Wreathall & Co's reports. A little after 1993 Wreathall suggests replacing "*latent error*" (referring to organizational failures) by "*latent failures*" that later became “*latent conditions*”. These changes acknowledge the fact that efficient decision at a given time may have negative outcomes another time or place in the system. Such decisions may not be wrong — they are just made under uncertainty – and thus may not be qualified a priori as *errors* but can still turn out to have adverse consequences in any other place or time. In addition to these semantic changes, SCM graphically evolves (over 4 times in the 1990s). Its use reached many sectors such as energy or transportation (Larouzée et al., 2014). During 1990s, Rob Lee, director of the Australian Bureau of Air Safety Investigation, suggested representing gaped barriers as Swiss cheese slices (Reason et al., 2006). The idea attracted Reason, then working on a new SCM version for the British Medical Journal (Reason, 2000; Fig 4). This was a landmark article (quoted 3442 times) and in 2003 Reason was appointed *Commander* of the British Empire for his work on patient safety. The SCM was born. Its simplicity and empirical pragmatism made it the vector of a new paradigm of Safety: the organizational accident.

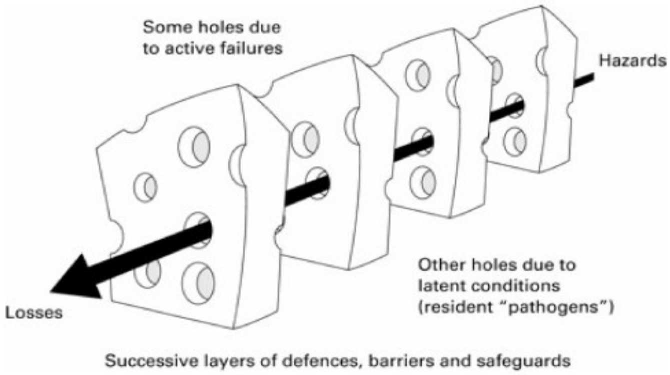

Figure 4. SCM version where the cheese slices represent a system’s defenses (Reason, 2000).

4 CONCLUSIONS

A detailed study of the SCM is both simple and complex. Simplicity comes from the abundance of sources. This model has been widely quoted and Reason is a prolific author (135 publications; Larouzée & Guarnieri, 2015). Thus, it is possible to trace the evolutions of the model and to harvest insights on the motivations of the changes. Once the right publications selected and compared, one can observe and follow the evolutions in the thought of the authors. By devoting attention to the prefaces and bibliographic references used, it is also possible to create a mapping of collaborators and networks of influences on the SCM. Finally, Reason and Wreathall played relatively distinct roles (one dedicated to academic publications of the SCM evolution, the other to its industrial applications). This duality prevents the theoretical reflections from being covered by confidentiality that often falls on industrial reports. On the other hand, complexity arises from the nature of the model’s origin: a collaborative and poorly documented work between distinct but interactive worlds, research and industry. Meeting the two fathers of the SCM was, in this regard, a great help. If it helps preventing from retroactive bias regarding the overall study, it also provides the opportunity to access new perspectives on their respective roles; new elements that can help to understand the success factors of their collaboration. Indeed, based on the fact that the SCM has been (for at least 15 years) at the industrial agendas, this study wondered (1) why is this model more than any others used in the industrial community at large and (2) is this model, conceptualized in the 1980s, still able to explain the accidents in 2015?

A tempting explanation of the SCM’s success is its simple graphical representation. If it is undeniable that Swiss cheese representation has played a role in the socialization process of Reason’s work, it actually seems it has mostly caused theoretical and methodological pitfalls (Larouzée & Guarnieri, 2014). A second hypothesis was that success of the model was the result of the appropriation of research findings by industry. It emerges that it is more the appropriation of industrial experience by the academics and long term collaboration that gave the SCM its empirical pragmatism, likely to encourage its use and spread. Working with the nuclear industry, James Reason became familiar with the engineer’s world. Faced with irreducible epistemological and ontological duality, the psychologist found the help of an engineer to coproduce the first model. Their meeting was helped by a favorable social and industrial context (Safety Culture decade and human error clambakes), their collaboration stood thanks to a mutual will of convergence. Let us note the importance of backgrounds and early life experiences that led Reason working in aviation community and Wreathall meeting systemic thoughts and human factors early in his studies. This shared background guaranteed sensitivity and brought a common language to the two: a collaboration prerequisite. Finally, more than causing their meeting, the social demand at that time (industry funding many research programs) allowed the evolutions of the model. Through various research programs the SCM was used and shaped to ensure its pragmatic rationality: that's how it became, along the 1990s, the vector of a paradigm shift in the safety science and industrial community.

This leaves us with one last question: is this theory (hardly changed since 2000), still able to explain today's accidents? The question is complex and maybe takes both a "no" and a "yes". Technologies have changed. Computers and technology at large is getting more and more involved in operating and even maintaining systems and some process are only ran by computers. Somehow, without having to call the SCM "linear" (which it isn't), one could consider it obsolete for highly automated systems. "No", the SCM doesn't explain how highly automated systems fail, to have a precise understanding of this kind of failure, one should turn to *control* based models such as STAMP (Leveson, 2011). On the other hand, humans haven't changed in a significant way in fifteen years. There are still pilots in airplanes cockpits, boats and train; there are still IT engineers designing machines; there are still top managers allocating budgets amongst departments; there are still operators in NPP rooms and surgeons in hospitals. Then "Yes", a simple and effective mean to understand what went wrong; to communicate about risks or to prevent adverse events may still be useful. Finally, let us remind that the SCM is nothing but a theoretical model. Tools have been made based on this theory (TRIPOD-B, TRIPOD-D, HFACS; see Larouzée *et al.*, 2014), the tools may need to be redesigned to match the evolution of our technologies: it doesn't mean the theory is obsolete. Accident still occurs because of the unwanted combination of technological failures (at some time and some degree), human failures (even if we should acknowledge here the *heroic ability* of humans to take control over a failed technical system; Reason, 2008) and organizational failures. As long as *the society* as a whole (politics, economics, Scientifics, engineers and so on) will keep buying news papers titling "*Investigators follow the lead of HUMAN ERROR*" the SCM will somehow have a contemporary interest.

5 DISCUSSION

Could similar collaboration between different researchers or disciplines bring the safety research further steps forward?

The Safety Science community seems to be in conceptual tension. The "active errors / latent conditions" paradigm on which is based today's accident prevention and analysis practices is challenged by the formulation of new theories (control, resonance, resilience, safety II ...). According to Kuhn's framework (1962), the safety science community, thus, goes through a period of scientific revolution. According to literature's reviews (e.g. Hollnagel & Speziali, 2008; Toft et al, 2012) one can highlight two perspectives when it comes to further development of theories and models accidents. To answer our discussion's question, we'll first try to characterize them and reflect on their respective implications.

First their shared statements should be exposed. (1) Accidents still happen, some are even recurring. (2) Theories and models available to professionals (therefore) haven't achieved the (theoretical) goal of accidents elimination or consequences reduction (the later would even tend to increase). (3) There is no model or specific method that can claim to be "the best" in all conditions. From that statements, two different research perspective seems to emerge.

A first logic is to assert that investigation methods (or models) do not represent the reality (complexity) of socio-technical systems "*Accident investigation methods [...] typically lag behind the socio-technological developments by 20 years or more.*" (Hollnagel & Speziali, 2012). Assuming that the nature of accidents depends on the nature of socio-technical systems (which remain to be demonstrated), this logic has assumed that the obsolescence of methods is related to the changing nature of socio-technical systems and therefore accidents: "*we must expect that the methods developed today will* [be] *partly obsolete, not because the methods change but because the nature of socio-technical systems, and therefore the nature of accidents, do*." (*Ibid.*). This view follows Charles Perrow's Normal Accident Theory, popularized in his 1884 book. I will group researchers using this logic under the label of "socio-technical gap school" (SG School). On the opposite, another logic argues that despite an increase in organizational and technical complexity, the nature of front-line operators' activities has not fundamentally changed (Hovden et al., 2010). Moreover, as acknowledged by Hollnagel & Speziali (2008) "*in terms of frequency or numbers, most systems are loosely coupled and [simple to describe] even today"* (p. 25). Thus, the evolution of accident models (from *simple linear* to *complex and non-linear*) is to be linked to the natural process of successive approximations used, over years, in accident modelling. Approximations being increasingly thin, models are being more complex (independently of systems evolutions). I will group researchers using this logic under the label of "conceptual gap school" (CG School).

The theories of these schools are incompatible and incomparable. Incomparable because there is disagreement among researchers about the issues to consider, possible solutions and definitions (which does not exclude conceptual or practical borrowings but for different uses). Working in different worlds, researchers see "*different things when they look in the same direction from the same point*" (Willett, 1996). Thus the SG school is working on the production of models that would explain a new world and will consider fashionable theories (including the SCM) as unable to grasp contemporary reality. The CG school's community works on the production of models that would continue to improve the understanding of a permanent phenomenon (accidents) and claim that SG school's productions are futile because too complex or, too far from the practices of safety professionals (including data collection and analysis; Roelen, Lin & Hale, 2011).

The ST school must be recognized that the effectiveness of dominant models can be questioned as accidents continue to happen. On the other hand, the CG school must be recognized that "new" and "efficient" are a non-correlated variable. Comprehensive studies show that systemic accident analysis models and methods are considered to be time-consuming and hard to understand by practitioners (e.g. Underwood & Waterson, 2013). This may partly explains that the SCM is still widely accepted and used in many industries, 25 years after its formulation. Moreover one should note that there is no neutral corpus of observations that would help choosing between two paradigms (hence the incommensurability and incompatibility of these). It is also necessary to keep in mind that the formulation of theories is a process adapted to the restrictive conditions of its production context (although this process can be systematic and controlled). *De facto*, theories are always partial, they emphasize a part of reality and therefore ignore everything else. "*A theory is not reality nor mean to reveal the truth* [but] *creates a reality that allows to design, perceive, understand and explain an aspect of the real in a logical and formal way. It is more fruitful to ask whether a theory is helpful rather than wondering whether it is true*" (Willett, *op. cit*.).

The recognition of the partial nature of a theory, of the complexity of accidents, the epistemological[4] weaknesses on which a "safety sciences" scientific community tries to build itself, lead us to positively answer the discussion question. Yes, similar collaboration (as we have characterized it, namely, (1) between engineering sciences and human sciences, (2) research and industry and (3) inscribed in duration) could bring the safety research further steps forward. More than an opportunity, such collaborations today seem a necessity in safety science research.

The accident is a phenomenon whose complexity involves convergence and collaborative approach. Failing in this collaborative effort might aggravate a damaging opposition between engineering and human sciences. Indeed, a paradigm is rarely questioned by experts who are followers. Nevertheless, "*some models, or a series of models, can perpetuate and conceal errors or fundamental inaccuracies, delaying the development of knowledge. Only by confronting these models with systematic observations and competing models can we get to detect these errors*" (Willett, op. Cit.). A theoretical rivalry that would seek to enforce "new models" over "old" one would be a waste of time in the development of knowledge for the prevention of accidents and live saving. A "double collaboration" between disciplines (to fill the partial nature of theories) and between research and industry (to confront models to reality and needs) seems to be able to serve this ethical and moral purpose.

This type of collaboration between disciplines and activities has been illustrated through the design and evolution of Reason's theory and SCM. It remains to refine our understanding of its success factors through the search and study of sufficient similar cases in order to ensure the development of such collaborations in the safety sciences.

[4] Fundamental questions have probably not been detailed enough claiming a necessary "pragmatic empiricism". If conceptualization is nothing but a prerequisite to action and cannot be a finality in itself, overcoming it is risky. The formulation of a theory involves the statement of a chain of interrelated proposals from deductions and using the intuitive logic. These proposals are then used to formulate testable hypotheses using the "scientific method" (strict measures whose results are a source of prediction or generate new observations or assumptions). But theories are based on concepts and explanations. Concepts must be clear, accurate, and unequivocal. This does not seem to be the case for "concepts" such as accidents, safety, or even complexity.

6 ACKNOWLEDGMENTS

The authors would like to warmly thank Professor James Reason for his hospitality, January the 7th, 2014, and to Mr. John Wreathall for coming and meeting us at MINES ParisTech Centre of Research on Risk and Crisis, October the 10th, 2014. Thank you to the anonym reviewers for their useful advices and the suggested discussion topic.

7 REFERENCES

1. J. LAROUZEE, F. GUARNIERI, D. BESNARD, *Le modèle de l'erreur humaine de James Reason*. Papiers de Recherche du CRC, MINES ParisTech. 44p. (2014).
2. J. LAROUZEE, F. GUARNIERI, *Fond bibliographique Sir James Reason – une vie dans l'erreur.* Papiers de Recherche du CRC, MINES ParisTech. 12p. (2015).
3. J. REASON, *Human error*. Cambridge university press. (1990).
4. J. REASON, D. EMBREY, *Principles Human factors relating to the modeling of human errors in abnormal condition of nuclear power plants and major hazardous installations*. Parbold, Lanes, Human Reliability Associates, (1985).
5. J. REASON, *Generic error-modelling system (GEMS): A cognitive framework for locating common human error forms.* New technology and human error, 63. (1987).
6. J. RASMUSSEN, *Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models.* Systems, Man and Cybernetics, IEEE Transactions. Vol:SMC-13, Issue: 3. (1983)
7. J. REASON, *Resident pathogens and risk management*. W.B. Workshop Safety Control and Risk Management. (1988).
8. INSAG, *Defense in depth in Nuclear Safety.* International Nuclear Safety Advisory Group Report (INSAG) IAEA. (1996).
9. J. REASON, Human error: models and management.BMJ, 320.7237. p: 768-770. (2000).
10. J. REASON, E. HOLLNAGEL, J. PARIES, *Revisiting the "Swiss Cheese" Model of accidents*. ECC No. 13/06. (2006).
11. J. LAROUZEE, F. GUARNIERI, *Huit idées reçues sur le(s) modèle(s) de l'erreur humaine de Reason*. Revue d'Electricité et d'Electronique. (2014).
12. N. LEVESON, *Engineering a safer world: Systems thinking applied to safety*. MIT Press. (2011).
13. J. REASON, *The human contribution.* Burlington, VT: Ashgate. (2008).
14. T. KUHN, *The stucture of scientific revolutions.* University of Chicago Press. (2012).
15. E. HOLLNAGEL, J. SPEZILI, *Study on developmens in accident investigation methods: a survey of the "state-of-the art".* SKI Reports. (2008).
16. P. UNDERWOOD, P. WATERSON, *Systemic accident analysis: Examining the gap between research and practice.* Accident analysis and Prevention 55. (2013).
17. Y. TOFT, G. DELL, K. KLOCKNER, A. HUTTON, *Models of causation: safety*. Safety Institute of Australia, Tullamarine, Victoria. (2012).
18. G., WILLETT, *Paradigme, théorie, modèle, schéma: qu'est-ce donc*? Communication et organisation. (1996).
19. A. ROELEN, P. LIN, A. HALE, *Accident models and organisational factors in air transport: The need for multi-method models*. Safety science, 49(1), 5-10. (2011).
20. J. Hoven, A. Abrechtsen, I. Herrera, *Is there a need for new theories, models and approaches to occupational accident prevention?* Safety Science, 48(8), 950-956. (2010).