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Reflecting on Jens Rasmussen's legacy. A strong program for a hard problem

Jean Christophe Le Coze *

Institut National de l'environnement industriel et des risques, Parc Alata, 60550 Verneuil en Halatte, France

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ABSTRACT

Jens Rasmussen has been a very influential thinker for the last quarter of the 20th century in the safety science field and especially in major hazard prevention. He shaped many of the basic assumptions regarding safety and accidents which are still held today. One can see that many of his ideas underlie more recent advances in this field. Indeed, in the first decade of the 21st century, many have been inspired by his propositions and have pursued their own research agendas by using, extending or criticising his ideas. The author of numerous articles, chapters of books and books, Rasmussen had an inspiring scientific research record spreading over 30 years, expanding across the boundaries of many scientific disciplines. This article introduces selected elements of Rasmussen's legacy, including the SRK model, his theoretical approach of errors, the issue of investigating accidents, his model of migration and the sociotechnical view. It will be demonstrated that Jens Rasmussen provided key concepts for understanding safety and accidents, many of which are still relevant today. In particular, this article introduces how some principles such as degree of freedom, self organisation and adaptation, defence in depth fallacy but also the notion of error as '*unsuccessful experiment with unacceptable consequences*' still offer powerful insights into the challenge of predicting and preventing major accidents. It is also argued that they combine into a specific interpretation of the 'normal accident' debate, anticipating current trends based on complexity lenses. Overall, Jens Rasmussen defines the contours of what is called 'a strong program for a hard problem'.

1. Introduction

1.1. Two articles on Jens Rasmussen's legacy

Jens Rasmussen, a pioneer in the field of safety science (with a focus on major accident research), continues to be of importance because of the lasting influence of his models and the ambition of his research program. The purpose of this study (that has been divided in two articles, there is a second proposed paper, to be submitted and published in the future), is to explore Jens Rasmussen's contribution to the field of safety science. This paper offers an overview of his key contributions over 30 years of cross disciplinary publications. Methodologically, approximately 30 papers have been reviewed in order to extract his key attributions to the field of safety. This overview shows the evolution of his intellectual journey, ranging from cognitive models, interface design, human error definition and human reliability, to accident investigation and socio-technical modelling. Several scientific disciplines are concerned including engineering, psychology, safety management, and the cross-disciplinary field of cybernetics. Secondly, the article shows how his thoughts and writings have influenced many key researchers in the field, indicating the importance of his ideas in the development of more recent ones. Authors with different disciplinary influences (e.g. psychology, management and sociology) and orientations in the field of safety (accident investigation, safety assessment, man–machine interface) have indeed incorporated in different ways Rasmussen's ideas into their studies, building upon different aspects of his research over several decades. In doing so, they have used, extended upon or criticised some of these ideas.

1.2. Preliminary remarks

Some preliminary remarks are in order. Epistemologically, philosophically or historically oriented papers in the field of safety, such as this one, are important, even if they do not have the practical focus that many safety scientists expect in an applied field of research. Despite living in a world of restricted resources in which the question "so what?" is inevitable, coming from one of the different participants in research institutions and industry who

* Tel.: +33 (0)3 44 55 62 04.
E-mail address: jean-christophe.lecoze@ineris.fr

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expect "practical" results, I am convinced of the value of this type of paper. A historical account of Jens Rasmussen's research is necessary. In my view, there are indeed several good reasons to do so.

First, the time has come to begin writing a history of safety science (oriented here on safety-critical systems). One way to establish a field and to delineate its boundaries for institutional reasons as well as its societal needs (e.g. preventing the repetition of technological disasters) is to look back at its founding fathers. One can easily find a similar approach in other fields (e.g. sociology, management, etc.). A second reason is to identify the issues and concepts found in the early phases of the history of a field which have become the basis for current research. It is important for a discipline to be able to agree and to reflect on the core scientific and philosophical topics that lay at the foundation of its own developments. Thirdly, I wish to reflect personally on where I stand intellectually and consider the direction of my own research in a cross-disciplinary topic. Looking back at the trajectory of authors can help us look forward. I seek to better understand how my ideas have been shaped by scientists in the field, a reason that is obviously interconnected with the two previous ones.

Fourthly, an investigation of the genesis of thought from the angle of the history of science allows us to understand how ideas take shape in their institutional context, be it scientific communities (e.g. safety science) or societal and industrial interests (i.e. research funds), as well as the historic scientific and philosophical context of theories and concepts (e.g. cybernetics in the case of Rasmussen). It also facilitates the understanding of how ideas take shape and the time scale of their genesis. Fifthly, this paper is aimed at promoting cross-disciplinary research. One difficulty for studying safety is its multidimensional nature and the need to find ways to combine models from different research traditions, including engineering, psychology, sociology, etc. There are many obstacles: cognitive (one must take the time to master models from different research orientations), social (a cross-disciplinary approach creates identity problems for researchers) and institutional (i.e. appreciation of interdisciplinarity by established disciplines, e.g. engineering, sociology, etc.). Finally, this paper offers safety science students an overview of the scientific contribution of an important author, Jens Rasmussen. In so doing, I seek to avoid simplification or misinterpretation of the author's views, understand current developments in the field, review new developments in the light of existing concepts, identify the extent of the author's legacy, but also the limits of his propositions and the opening of new perspectives.

2. Methodology

Methodologically, I identified the core themes and concepts in his writings, beginning with his early papers (i.e. Rasmussen, 1969, 1976) through the later ones (i.e. Rasmussen, 1997a; 2000) To do so, I have read not only Rasmussen's published journal articles but also chapters in books (see Rasmussen's references). I have not included in this review books authored by Rasmussen (or those written in collaboration), nor the Risø reports (except one), as I believe all his essential ideas would have been published in his articles. Whereas the Risø reports may provide more conceptual and historical elements, their study is not necessary in this context. Indeed, Rasmussen's legacy is for the most part a product of his published articles, easily accessible to the community of safety scientists. Only a very restricted readership has access to these reports.

In reviewing the published articles, I focused on five aspects. First, I traced the introduction of new ideas, principles, concepts and models. Many quotes from Rasmussen are thus used in this article in order to provide readers direct access to his expressions and ideas. Second, I have tracked the evolution of principles, concepts and models. I have tried to understand how one concept in a domain was translated or transferred to another. I have also paid attention to the analogies or metaphors employed, whether they were borrowed from engineering, physics, biology, or psychology, etc. This is an important part of any scientific work, as we know that induction and deduction are to be understood in relation to abduction (analogy), a pattern recognised to be at the heart of scientific intuitions and creativity. Selected figures illustrate some of these evolutions. Third, I have taken note of the empirical approach used to ground model development, be it primary or secondary data, normal operation or accident, experimental or real life studies, qualitative or quantitative approaches, etc.

Fourth, I have identified the various topics addressed throughout the papers (e.g. interface design, human error, etc.) and tried to understand how shifts in subjects could be related to specific historical circumstances (e.g. major accidents, global evolution in safety concerns, development of research communities or networks). For these three steps, I have proceeded chronologically. I determined a timeline and a global pattern of how his research interests and focuses evolved over the years, but also how some of these shifts could be understood in relation to what I know of the historical context. Finally, I have tried to take a step back and look for main influences behind Rasmussen's ideas. I tracked what I thought to be a core intellectual matrix explaining the diverse models and concepts presented in the articles. To do so, I considered both concepts but also authors frequently mentioned in his writings, who were cited earlier or later in his research (this final aspect will be treated separately, in a second article with a different subtitle 'behind and beyond, a 'constructivist turn').

In conjunction with these steps, I have identified authors in the field of safety science who have used Rasmussen's principles, concepts and models. To do so, I have primarily focused my research on human and social science journals related to safety as well as safety related books. These authors are sometimes critical of his ideas; they have sometimes transformed, applied or expanded upon them. I have selected some of these authors for this article in order to give a notion of his legacy. This study is not exhaustive. I seek to be representative, not comprehensive. Finally, I have reflected upon my own approach in regards to his legacy.

2.1. Article sections

Based on the methodology described above, in Sections 1–7 of this paper, I introduce and discuss the key and enduring available concepts of Jens Rasmussen in the field of safety (box 1). For each of them, I present their genesis and some of the debates surrounding the issues that they introduce. I select and refer to authors in safety science who criticise, employ or develop Rasmussen's legacy.

Box 1 List of key concepts from Rasmussen discussed in the paper.

1. Modelling process plant operator in relation to display engineering,
   a. human data processing mechanisms,
   b. ladder of abstraction and levels of behaviour 'SRK'.
2. Conceptualising 'human error' as an "*unsuccessful experiment with unacceptable consequences*",
3. Contrasting technical and human reliability/safety analysis,

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