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Editorial

Recurring themes in the legacy of Jens Rasmussen

1. Introduction

The work of Jens Rasmussen over the course of the last half century represents some of the most influential contributions to the fields of cognitive science, human factors, ergonomics and safety science. His work has inspired researchers and practitioners in a number of fields including psychology, organisational behaviour, engineering and sociology (Le Coze, 2015). Early work on the Skills, Rules, and Knowledge taxonomy for example, was instrumental in fostering the development of models of human error during the 1980s and 90s (e.g. Norman, 1981; Reason, 1990). In more recent years, a large amount of research has drawn on theoretical and practical aspects of Rasmussen's work including his models of the boundaries of safe operation, ecological interfaces and methods such as cognitive work analysis. Rasmussen's work on the Risk Management Framework (Rasmussen, 1997) has been cited over 1000 times since its original publication in 1997 and the extent of his influence across the wider research community is growing at a fast rate (Wears, 2015). His research has taken on renewed relevance and importance in the light of recent large-scale systems disasters and accidents (e.g. Fujushima Daiichi, Deepwater Horizon, and South Korea Ferry Disaster – Jun et al. and Lee et al., *this issue*), as well as recent developments in the fields of normal accident theory (Perrow, 1984), resilience engineering (Hollnagel et al., 2006) and the high reliability organisation (Weick and Sutcliffe, 2007; Le Coze, 2016a).

2. Origins and aims of the special issue

The idea for the collection of papers in this special issue first came about through a conversation between two of the editors (PW and HBA) at a meeting of the Resilience Healthcare Network in Middelfart, Denmark in June 2012. Both of us agreed that there was a need to provide opportunities for researchers to discuss the work of Jens Rasmussen and the subsequent impact he has had upon research carried out in the last few decades since the publication of a Festschrift in 1988 (Goodstein et al., 1988). The third editor (JCLC) was involved in independently exploring Rasmussen's work (Le Coze, 2015, *this issue*) and helped to organise together with the other editors in August 2014 a two day symposium entitled 'The legacy of Jens Rasmussen' at the ODAM 2014 conference in Copenhagen, Denmark (www.odam2014.org/Legacy). The second day of the symposium took place at Risø and a total of 31 participants drawn from the USA, Australia and Europe took part and ten papers were presented. In addition, we were contacted by a number of other prominent authors in the fields of human factors and safety science who were unable to attend the symposium, but expressed in contributing to the special issue. The symposium captured elements of Rasmussen's past work, as well as new directions and developments based on his work and much of this is captured in the current special issue.

A key aim of the special issue is to re-examine the work of Jens Rasmussen in the light of recent developments in human factors and safety science. A second aim is to examine the future of human factors as it applies to safety, accidents and human error. In this editorial we first provide some further details on the life and work of Jens Rasmussen and major developments in his career (Section 3). Section 4 of the editorial attempts to put Rasmussen's work into a broader context through looking at the development of four of influential publications across the period 1974–1997. Based on the analysis of these and other publications, alongside the contributions from the 15 papers in the special issue, we identify a set of recurrent themes in the Rasmussen legacy which are discussed in Section 5 of the editorial. A final section (Section 6) points the way forward to future plans by the authors and others to further celebrate and continue on with Rasmussen's legacy. We are also very grateful for a final paper provided by Penny Sanderson and Cathy Burns which provides further reflections on the legacy and the papers in the special issue.

3. Jens Rasmussen: a brief overview of his life and work

After his M.Sc. degree in electronic engineering in 1950 and a few years at the Radio Receiver Research Laboratory, Rasmussen was recruited, in 1956, by the Atomic Energy Commission to prepare the design of the control room for the then planned nuclear research reactor at Risø, a small peninsula in Roskilde Fjord in Denmark. A few years later, at the age of 36, Jens was appointed head of the Electronics Department at the Atomic Research Establishment Risø (later Risø National Laboratory) – a position he held for 25 years until he was appointed Research Professor at the Technical University of Denmark and at Risø. From the very beginning as department head, Rasmussen's primary responsibilities were to lead the instrumentation of the control room and support the development and maintenance of the various scientific measurement equipment of the facility, and most of his work during the first five to six years was focused on largely technical aspects and reliability. During this time he became gradually increasingly interested in the interplay between operators and the instrumentation, cognitive requirements to displays and, indeed, operators' reactions and behaviour under abnormal conditions, revealed in the titles of some of his early papers from this

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period: 'Man-Machine Communication in the Light of Accident Records' (1968) and 'On the Communication between Operators and Instrumentation in Automatic Process Plants' (1969). Appendix 1 highlights some milestones in the development of Rasmussen's ideas about the role of design and human operators in system safety. Further details both of the history of Cognitive Engineering at Risø and the larger worldwide context in which this took place (e.g. the Three Mile Island and Chernobyl nuclear accidents) are provided in other publications by Vicente (1997), Nielsen (1998) and Sheridan (2003; *this issue*). We should also note that Kant (*this issue*) provides an in-depth treatment of Rasmussen's work over the period 1961–1986.

4. A closer look at four influential papers

The papers in this section of the editorial were selected in order to show the progression of Rasmussen's thought over three decades. Each of the papers is summarised, followed by an attempt to link them to either similar work during that decade or later work research which has been directly or indirectly influenced by the paper. We should emphasise that summarising and assessing the implications of Rasmussen's work is not an easy task. His work is often grounded in a larger philosophical and conceptual context and reflects deep and wide reading across a diverse and extensive range of disciplines. Likewise, papers written over 40 years ago resonate with current developments in the fields of human factors/ergonomics and safety science. Our principle aim in the current paper was to capture some of our own impressions of the papers and the influence they have had.

4.1. Mental procedures in real-life tasks: a case study of electronic trouble shooting (Rasmussen and Jensen, 1974, Ergonomics 17, 3, 293–307)

4.1.1. Summary

This paper provides an account of the use of 'protocol analysis' to explore the mental processes involved in problem solving by electronic technicians. In the late 1960s and early 1970s the analysis of verbal protocols from operators as they carried out their tasks (e.g. process control operations) became popular amongst research workers (e.g. Bainbridge, 1969; Bainbridge and Sanderson, 1996). Rasmussen and Jensen observed the process technicians used when diagnosing problems with electronic instruments (e.g. oscilloscopes, TV displays). The paper, although written in the early 1970s is interesting for a number of reasons, not least the way in which it anticipates later developments in Rasmussen's thinking, but also subsequent developments and trends in cognitive science and human factors. For example, the study showed that the most common form of problem solving involved "topographic search": technicians organised their search for the fault based on the physical layout of the circuitry. Fault finding involved an iterative process of making good or bad judgements until they had identified the problem with the circuit. The process, although involving many redundant tests, took little time and was generally efficient. The process was also efficient in terms of the load it placed on working memory; technicians took advantage of the natural constraints built into the task (i.e. the wiring typography) and were able to offload some of the computational demands on the search. Naikar (*this issue*) provides an interesting example of some of the original illustrations from the Risø technical reports (Naikar, *this issue*) which gives some sense of the nature of the complex problem solving (interweaving purposive and physical properties of the task) they were carrying out.

4.1.2. Relation to other work

This account of problem solving contrasts with the classical information processing models which were dominant at the time (e.g. Newell and Simon, 1972; Lindsay and Norman, 1972) and emphasised a set-by-step problem process which relied more on internally stored representations of the problem. Rasmussen's and Jensen's paper by contrast, acknowledges the role played by external representations in structuring the problem space (Newell, 1980). From this point of view actions and reasoning unfold as an integrated and continuous flow, where no discrete actions and decisions are taken separately (Carim Jr. et al., 2016). One of the characteristics of the study, and something which might be said to be recurring theme in Rasmussen's work (Section 5 of this paper), is that it on the one hand harks back to earlier work which emphasises the role played by the environment on cognition and the inter-relationships between various data sources and mental representations involved in complex work tasks (in the case of this paper, Bartlett, 1958; Craik, 1943), but also crucially anticipates or points forward to later developments (e.g. 'distributed cognition' the use of graphical representations to solve problems and the theory of mental models – Hutchins, 1995; Scaife and Rogers, 1996; Johnson-Laird, 1983). Similar parallels can be drawn with other parts of the paper which read today like early descriptions of the use of 'early warnings and 'weak signals' (Macrae, 2014) or implicit memory (Broadbent et al., 1986) by technicians to provide cues to likely faults:

> 'In some cases 'feelings' of the location of the fault are stated, which are contradictory to the observations just recorded, but nevertheless correct in agreement with information which the man, according to the earlier recorded procedure did not mention' (Rasmussen and Jensen, 1974: 296).

Finally, the paper makes a strong commitment to the importance of carrying out real-life observations of complex work, as opposed to laboratory tasks or problems. This is particularly the case in terms of the value observational work may have for the system designer and the dangers of over-rationalising how tasks may actually be carried out. The following statement from the paper also resonates with current preoccupations with the notion of 'work as done vs. work as imagined' within the 'Safety II' movement (Hollnagel et al., 2015; Section 5):

> *'The system designer with his theoretical background may quite naturally value as rational the 'elegant' deductive procedure which is informationally very efficient and based upon few observations, but this criterion will not be an appropriate one to judge performance in real-life maintenance work. It is important that system designers preparing working conditions and involved with the training become aware of this difference in task formulation and performance criteria …* (Rasmussen and Jensen, 1974: 306).

4.2. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models (Rasmussen, 1983, IEEE Transactions on Systems, Man, and Cybernetics, 13, 3, May/June, 257–266)

4.2.1. Summary

In contrast to the detailed protocol analysis of technician's problem solving provided in Rasmussen and Jensen, (1974), this paper offers a much more conceptual and philosophically grounded account of what Rasmussen refers to as 'the human as data processor' (Rasmussen, 1983, p. 261). As illustrated by a well-known quote from Herbert Simon (the 'ant on the beach' example) in an earlier