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Understanding human performance in sociotechnical systems – Steps towards a generic framework

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ABSTRACT

Humans, their performance, actions and decisions play a significant role in a vast range of operations in complex sociotechnical systems. Numerous studies have therefore endeavoured to understand people's actions and/or inactions within their working environment and to identify those factors, also known as Performance Shaping Factors (PSFs), that contribute either positively or negatively to sociotechnical system performance. However, the majority of those studies are often created based on data and research derived from a specific domain, and therefore are difficult to apply beyond the domain of interest. Thus, this paper presents a generic framework to develop a standardised list of PSFs, referred to as (Cross-Sectoral Performance Shaping Factors, C-PSFs), to be used across sectors to describe the immediate and latent factors that affect human performance in a structured and consistent manner. Building upon the existing Railway-Performance Shaping Factors taxonomy and the fundamental concepts of Cognitive and Behavioral Science, the new C-PSFs taxonomy illustrates the numerous possible interdependencies between the human operator and a system's constraints. The former provides the empirical evidence for the C-PSFs taxonomy's generic factors, while the latter justifies the transferability and applicability of the taxonomy to a broad range of sociotechnical sectors. The analysis of two accidents, from the railway and energy sectors, support such evidence. The proposed taxonomy provides a common baseline set of PSFs across sectors and its usage can greatly improve safety management systems of cross-sectoral organisations.

1. Introduction

Human performance, actions and decisions play a significant role in a broad range of operations in complex sociotechnical systems, from routine to abnormal conditions, to major shocks or emergencies. On some occasions, humans have been notably successful in coping with a (unexpected) situation, e.g., the US Airways flight water landing in the Hudson River (NTSB, 2010). In other instances, attempts have been unsuccessful and highlighted the organizational and operational shortcomings of the facility's/utility's preparedness, such as that involving the Space Shuttles Challenger (Dekker et al., 2008; NASA, 1986; Nemeth and Herrera, 2015) and Columbia (Dekker et al., 2008; NASA, 2003; Nemeth and Herrera, 2015), as well as Fukushima Daiichi nuclear power station (Amir and Juraku, 2014).

Research has therefore broadly endeavoured to understand people's actions and/or inactions within their working environment. In particular, the general trend has been to identify those factors, also known as Performance Shaping Factors (PSFs), that contribute either positively or negatively to human performance (Boring et al., 2007; Forester et al., 2006; Gertman et al., 2004; Groth, 2009; Hollnagel, 1998; Kirwan, 1994; Lois et al., 2009). The PSFs encompass a vast range of possible factors from human-machine interface ergonomics, procedural guidance, to training, experience, and organizational safety culture. Detailed retrospective analyses of accidents and incidents in different domains has led to the identification and creation of various sectoral PSF taxonomies aiming at providing the relevant stakeholders with means to improve safety and enhance accident prevention by better understanding human performance. Such taxonomies are often created based on data and research derived from specific domains, such as the nuclear, aviation, and healthcare sectors (Bell and Holroyd, 2009; Hollnagel, 1998; Kirwan, 1994;

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Kyriakidis, 2011). Many PSF taxonomies are sectoral (Kim and Jung, 2003), while efforts have also been made to develop more generic PSF taxonomies (Hollnagel, 1998). One of the distinctions between the sectoral taxonomies and the generic PSF taxonomies is the level of detail. The generic taxonomies tend to be defined at a high level, where they are associated with the elements of practically any system, i.e. the operators, the human-machine interface, the system's physical response and corresponding signals and cues; on the other hand, the sectoral taxonomies, defined at a lower level of classification, are more differentiated because they are "connected to more contingent and detailed characteristics" of a specific system and domain (Onofrio et al., 2015). This contingent differentiation means that a PSF is in general applicable whereas the rating scales are more difficult to apply across sectors. For example, in a highly proceduralized domain, procedures are available to cover a large number of situations and a procedure may be rated poor because its prioritization is not clear in a specific situation; in contrast, in a less proceduralized sector, the only available procedures are general, not address many abnormal situations, and rare scenarios may not be covered by any procedures at all. In this example, average performance conditions and baseline human reliability will be very different. The PSF "noise" is a second example. In a (surgical) operating theatre, noise consists of non-task-related talk (Onofrio et al., 2015); in an industrial environment, a noisy environment may refer to equipment noise that requires ear protection, with its impact on auditory perception of alarms or on the ability to communicate.

Thus, a prerequisite for learning from such PSF taxonomies is to construct them in ways that capture the generic aspects of man-machine interaction along with the characteristics of the specific technological domains. In addition, with the increasing awareness of various facets of human cognition and activity, using these viewpoints to develop a framework will support a more integrative view of human performance in system safety. While, previous frameworks have adopted an enhanced insight into human cognition, the growth of post-cognitivist theories have highlighted human cognition not as an attribute of the person but an emergent relation between people and their technological contexts (e.g., ecological psychology, Gibson, 1979, prominently used in human factors, is a post-cognitivist approach). In terms of the safety of a system, beginning from these new assumptions sensitizes the safety researcher to situations that were not completely characterized by previous approaches. Further, constructing or identifying a set of generic performance factors in a comparative approach would in turn enable an analysis of human-technology interaction that transcends the particularities of any single technological domain and, crucially, allow trans-sector learning, safety enhancement, and accident prevention.

The role of human performance in complex sociotechnical systems is currently being investigated within the Future Resilient Systems (FRS, 2015) project, which aims to explore novel approaches towards designing and developing robust and resilient critical infrastructure systems. Within this context, this study presents preliminary steps towards the development of a generic framework to study human performance and identify the associated PSFs in a broad range of cross-sectoral operational contexts. This new framework is built upon the Railway Performance Shaping Factors (R-PSFs) taxonomy (Kyriakidis et al., 2012, 2015), and the fundamental concepts and themes derived from Cognitive and Behavioural sciences. The R-PSFs taxonomy was chosen due to its holistic, bottom-up development approach and complemented by the top-down theoretical basis along with the generic themes and concepts from the cognitive and behavioural sciences. The R-PSFs taxonomy was created following an extensive literature review in the field of Human Factors and Human Performance Analysis (HPA) techniques, studying and incorporating sixteen taxonomies from several domains, such as nuclear, transportation (aviation and railway), oil and gas (Kyriakidis et al., 2015). The literature findings were then corroborated by empirical data derived from the analysis of 479 railway accidents and incidents worldwide, while results were further validated by a Subject Matter Experts (SMEs) study (Kyriakidis et al., 2015). Next, in order to consolidate the R-PSF components for the basis for the development of a generic cross-sectoral taxonomy, the concepts and generic themes from Cognitive and Behavioural Sciences were employed. This is used as means not only to assure the transferability of the R-PSFs factors, based on a generic and well-acknowledged, theoretically-founded approach, but also to highlight all the possible interactions between the human operators and a system's constraints in the context of sociotechnical systems.

Subsequently, this study contributes to bridging the lack of a standardised list of PSFs that could be used across sectors to describe the immediate and latent factors that affect the performance of operators and other specialized personnel in a structured and consistent manner. Such a list of PSFs, referred to as Cross-Sectoral Performance Shaping Factors, hereafter C-PSFs, could be included in the investigation scheme across sectors, and enhance the current methods for capturing and identifying the most common contributing factors involved in human attributed operational incidents and/or accidents. The response of non-specialized personnel in abnormal situations and emergencies is not in the scope of this study and is not discussed here. In future work, we intend to examine how this framework could be applied in the analysis of responses, such as how the public may behave during evacuations, how transport users may act during disruptions, because the factors included in the C-PSFs taxonomy are also applicable in such situations, at least at a high level.

This paper is divided into six sections. Section 2 discusses the role of PSFs in addressing the human role in complex sociotechnical systems, while highlighting the challenges in constructing a generic taxonomy for studying human performance in such systems. Section 3 introduces the generic themes and currents of thought from cognitive and behavioural sciences that will be required for addressing the conceptual categories of the taxonomy. Based on these generic categories the new taxonomy is proposed in Section 4, and Section 5 then presents the case study of a railway-based incident, analysed in both the terms of the existing Railway-PSFs taxonomy, as well as the new proposed taxonomy, referred to as Cross-Sectoral Performance Shaping Factors (C-PSFs). The analysis shows that the two taxonomies converge on specific aspects, as well as the fact that Railway-PSFs can be squarely folded into the proposed taxonomy. This demonstrates that the theoretically motivated C-PSFs taxonomy is commensurate with the empirically derived R-PSFs. To show the broader applicability of the proposed taxonomy, and its applicability to other sectors, the analysis of an event in the energy sector is demonstrated in Section 6. Finally, Section 7 summarises the findings, discusses the future direction of the proposed taxonomy and the ways it could be used for cross-sectoral analysis of highly complex sociotechnical systems.

2. The role of performance shaping factors in addressing the human challenges in sociotechnical systems

"Without understanding the purpose, goals, and decision criteria used to construct and operate systems, it is not possible to completely understand and most effectively prevent accidents" (Leveson, 2004, p. 243).

One of the most fundamental challenges in complex sociotechnical systems is the role of humans in completing the human-automation-technical loop to achieve safe and reliable operations. Humans in those systems are involved in a vast range of roles,

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