Safety Science 111 (2019) 80–93

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Visualising safety: The potential for using sociotechnical systems models in prospective safety assessment and design

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ARTICLE INFO

Keywords:
Safety
Safety assessment
Sociotechnical systems
Human factors/ergonomics
Systems ergonomics

ABSTRACT

There is growing emphasis within safety science and Human Factors/Ergonomics on the benefits of applying a sociotechnical systems perspective in order to influence design and thereby improve safety in everyday operations. This article examines how viewing work as a sociotechnical system – using visual models and representations – helps in understanding how work is performed and how it contributes to safe operations. A series of five models, developed using methods from Activity Theory, Cybernetics, Cognitive Systems Engineering and Resilience Engineering, are used to illustrate the work of maritime pilots and Vessel Traffic Services operators. Each model is examined using a modelling framework for prospective safety assessment, with the conclusion that it is how the models are applied, rather than their underlying methodologies, which determines their usefulness in this context. Different models highlight different aspects of work and facilitate discussion of safety, for example in a participatory design process, and we discuss criteria to guide their use and evaluation.

1. Introduction

'Good ergonomics is systems ergonomics' (Wilson, 2014). Viewing work in terms of the interaction between humans and other parts of a sociotechnical system, with the intent of incorporating this understanding into design, is becoming increasingly common in Human Factors and Ergonomics (HF/E) theory and practice (Checkland, 2000; Hollnagel, 2014a; IEA, 2018; Wilson, 2014). A sociotechnical systems view can enhance the ability to design for safe operations (Hollnagel, 2014b; Le Coze, 2013a,b; 2017; Rasmussen, 1997); it may be necessary to prospectively anticipate the impact of new technologies (Hollnagel, 2014a). Similarly, within safety science, in particular the fields of Resilience Engineering (Hollnagel et al., 2011) and Safety-II (Hollnagel, 2014b), there is growing interest in viewing work as a sociotechnical system and understanding how safety manifests itself in its practice, investigating how this differs from, or complements, safety through compliance (e.g. Hale & Borys, 2013; Hollnagel, 2012, 2014b). Unfortunately, there are many interpretations of what a 'systems view' actually means (Wilson, 2014) and one may easily become disoriented in the 'acronym soup' of systems approaches to design (Hoffman et al., 2002). One common element or starting point within HF/E is that, in order to design a system, process or artefact which fulfils its purpose, one must first understand how work is performed (Wilson, 2014).

However, much modern work is invisible except to those performing it; indeed, 'the better work is done, the less visible it is to those who benefit from it' (Suchman, 1995:58). We should be sensitive to the complexities of work, and wary of thinking that these can easily be 'revealed, "captured", analysed into constituent part and transformed into manipulable, objectified knowledge' or represented as 'rationalizable, abstract function/processes, enacted through specific behaviours/practices' (Suchman, 1995:60). In safety-critical domains – such as aviation, nuclear, healthcare, offshore and maritime – successfully capturing how essentials such as monitoring and controlling (e.g. Praetorius & Hollnagel, 2014; van Westrenen & Praetorius, 2012) and the use of tacit knowledge (Mikkers et al., 2012; Praetorius et al., 2015) are performed is therefore a pressing challenge for system design (Hoffman & Lintern, 2006).

This paper will concentrate on one case of sociotechnical work in a safety-critical domain: *navigational assistance*, a collective term for services intended to improve the safety of navigation of seagoing vessels, performed predominantly on board vessels by maritime pilots or from shore by Vessel Traffic Service (VTS) operators. It aims to show how *literally viewing work as a sociotechnical system* – i.e. visualising the work of pilots and VTS operators using five systemic representations or models informed by sociotechnical systems theories - may aid in understanding how work is performed, and how it contributes to safe operations. Furthermore, it discusses a pragmatic approach to using such visual representations to aid integration of operator knowledge

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https://doi.org/10.1016/j.ssci.2018.09.003
Received 16 October 2017; Received in revised form 15 May 2018; Accepted 5 September 2018

into design, thus proactively addressing safety challenges (see also Rasmussen, 1997; Waterson et al., 2017). It builds on the premise that, for a model to fulfil this purpose, it must be capable of communicating critical aspects of work to designers, managers and other stakeholders (Le Coze, 2013a,b; also Broberg et al., 2011; Shorrock and Williams, 2016). It presents a framework with four requirements for a sociotechnical systems model which may be used to this end (developed by Le Coze, 2013a), and discusses how it may be used and evaluated in practice.

After a short introduction to navigational assistance (Section 2.1), Le Coze's framework and the five models will be introduced (Section 2.2). Section 3 describes the methods of empirical data collection and analysis (3.1), and presents each of the five models (3.2), their underlying methodologies and salient features, then summarises and compares what each of the models show us. Section 4 discusses the potential for using sociotechnical systems models in prospective safety assessment, first making a pragmatic argument for the use of the framework (4.1), then investigating how it may be used and evaluated in practice (4.2). The article concludes (Section 5) that the extent to which a model fulfils the requirements is largely an analytical choice, but will result in a 'better' model for use in design and safety evaluation; we provide suggestions for further work on how this may be achieved in practice.

2. Background

2.1. Navigational assistance: a case of safety-critical sociotechnical work

Navigational assistance aims to improve the safety of navigation of seagoing vessels, especially in areas where enhanced safety measures are deemed necessary, due to risks presented by geography, weather patterns or traffic density (IALA, 2016; IMPA, 2014). Pilotage comprises 'activities related to navigation and ship handling in which the pilot acts as an advisor to the master of the ship' (IALA, 2012:10) in order 'to guide vessels into or out of port safely - or wherever navigation may be considered hazardous, particularly when a shipmaster is unfamiliar with the area' (IMO, 2018). Vessel Traffic Services (VTS) is a shore-based service, which aims to 'improve the safety and efficiency of vessel traffic and to protect the environment' (IMO, 1997:3) and 'aid the mariner in the safe use of navigable waterways' (IALA, 2016: 27).

Previous research has viewed the work of pilots and VTS operators as a complex sociotechnical system, both separately and as a single, distributed system, through the lens of Cognitive Systems Engineering (CSE) as a Joint Cognitive System (JCS) (e.g. van Westrenen & Praetorius, 2012; Praetorius & Hollnagel, 2014), and Resilience Engineering (RE) (e.g. Mikkers et al., 2012) and its associated Functional Resonance Analysis Method (FRAM) (Praetorius et al., 2015; also de Vries 2016a, 2017). This body of work shows the value of modelling navigational assistance in its various forms as a sociotechnical system, highlighting the interaction between pilots, VTS operators and their work systems and environment. It also shows the importance of eliciting the knowledge of practitioners - through qualitative methods such as observations, interviews and focus groups - when attempting to understand and describe the practice of work. It increases the knowledge of how pilots and VTS operators work to improve safety and indicates considerations which should be taken into account when designing future systems or implementing change, but stops short of providing concrete recommendations. This article aims to go one step further and explore how this may be achieved in practice.

2.2. A framework for prospective safety assessment and design

Le Coze (2013a) describes a framework consisting of four requirements for a modelling approach which may 'better grasp in foresight what is being interpreted in hindsight' (2013a:1), thereby going beyond understanding and describing work, to assessing safety and by implication informing design and prospectively evaluating the impact of change. Although developed in the context of safety models, we extend the framework to apply to sociotechnical systems models in general, drawing on the work of Rasmussen (1997; Rasmussen et al., 1994) and Hollnagel (2012, 2014a,b; Hollnagel & Woods, 2005) in bridging the gap between the fields of HF/E and safety science (see also Le Coze, 2017; Stoop and Dekker, 2012; Waterson et al., 2017). It describes a 'sensitising' model which brings together elements of systems thinking with insights from sociology and 'softer' work studies traditions (also advocated by e.g. Checkland, 2000; Haavik et al., 2016; Hepsø, 2014; Wilson, 2014). It addresses the need to avoid simplification, firstly in terms of level of detail (an inherent problem in any modelling approach), and also recognises that work is usually performed (and changed) within an organisational or regulatory context, and encourages a dialogue, not a polarisation, between safety in principle and in practice (see also Grøtan, 2013; Hepsø, 2014). It seeks to reconcile the top-down safety management approach typical within industry (often described as 'theory 1', 'model 1′ or 'work as imagined') with bottom-up practitioner experience ('theory 2' , 'model 2' or 'work as done'; see e.g. Hale & Borys, 2013; Hollnagel, 2012, 2014b), in order to design a system which can proactively address safety challenges. The four requirements (Le Coze, 2013a:194) are:

1. first, one needs a generic model, not specific to one case but with a potential for relevance across a variety of technological and social configurations, a model that is generic enough to sensitise without destroying the distinctiveness of real cases (a 'sensitising model');
2. second, one needs to strike a balance between a descriptive and a normative posture, between what 'is' and what 'should be'; one cannot only rely on a descriptive and neutral approach as this would mean that no assessment could be provided;
3. third, one needs to grasp several nested layers of analysis to capture the patterns identified retrospectively in accidents by social scientists, and this requires the introduction of the micro–meso–macro-systemic and dynamic link;
4. fourth, one needs to produce a model that is not too simple, to capture phenomena that are multidimensional, but not too complex either, in order to serve its purpose of being useful for safety assessment, e.g. not to be rejected by people without a strong social sciences background.

This fourth requirement encapsulates the challenge of modelling for the purpose of design of sociotechnical work, rather than analysis: in order to 'serve its purpose', *evaluating safety* and *influencing design*, a model must also be capable of communicating between multi-disciplinary stakeholders (see also Shorrock & Williams, 2016; Waterson et al., 2017). Latour (1986) contends that it is precisely this ability of visual representations to *mobilise* information which enables them to be easily transported from one setting to another, or between actors distributed in space and time, without transforming the essence of the phenomena they represent. We will propose that this may be achieved in practice by using system models to facilitate discussion between multidisciplinary actors, treating them as as *boundary objects* which 'constitute means of communication and are enablers of participatory design processes' (Broberg et al., 2011:1; also Karlsson, 1999; Hepsø, 2014) and discuss some guidelines to facilitate the participatory process.

In this article, navigational assistance will be presented in visual form using five models derived from different systems perspectives: **Activity theory** (Bødker & Klokmose, 2011; Engeström, 2000); **Cybernetics** (Wiener, 1948; Skyttner, 2005; also Hollnagel & Woods, 2005); models from two branches of **Cognitive Systems Engineering (CSE)** (Rasmussen et al., 1994), namely **Joint Cognitive System (JCS)** (Hollnagel & Woods, 2005) and **Work Domain Analysis (WDA)** (Lintern, 2009; Naikar, 2017; Naikar et al., 2005); and **Functional Resonance Analysis Method (FRAM)** (Hollnagel, 2012; Hollnagel et al., 2014). Although each of these perspectives highlights