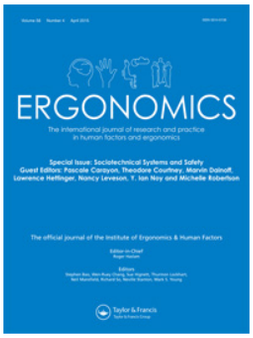

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Editorial: emerging issues in sociotechnical systems thinking and workplace safety

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The burden of on-the-job accidents and fatalities and the harm of associated human suffering continue to present an important challenge for safety researchers and practitioners. While significant improvements have been achieved in recent decades, the workplace accident rate remains unacceptably high. This has spurred interest in the development of novel research approaches, with particular interest in the systemic influences of social/organisational and technological factors. In response, the *Hopkinton Conference on Sociotechnical Systems and Safety* was organised to assess the current state of knowledge in the area and to identify research priorities. Over the course of several months prior to the conference, leading international experts drafted collaborative, state-of-the-art reviews covering various aspects of sociotechnical systems and safety. These papers, presented in this special issue, cover topics ranging from the identification of key concepts and definitions to sociotechnical characteristics of safe and unsafe organisations. This paper provides an overview of the conference and introduces key themes and topics.

Practitioner Summary: Sociotechnical approaches to workplace safety are intended to draw practitioners' attention to the critical influence that systemic social/organisational and technological factors exert on safety-relevant outcomes. This paper introduces major themes addressed in the *Hopkinton Conference* within the context of current workplace safety research and practice challenges.

Keywords: sociotechnical systems; occupational safety; complexity

1. Introduction

The creation of sustainable and safe work environments is a vital international concern. While reliable statistics on global work-related injuries, fatalities and their associated financial costs are unavailable, figures from the USA alone provide a compelling indication of the magnitude of the problem. According to the 2013 Liberty Mutual Workplace Safety Index (Liberty Mutual Research Institute for Safety [LMRIS] 2013), the cost of the 10 most disabling workplace injuries and illnesses in the USA in 2011 (the most recent year for which statistics are available) amounted to more than $55 billion in direct workers compensation costs alone. Considering indirect and other costs, overall annual costs could amount to more than $250 billion (Leigh 2011). In one of the few systematic summaries of global occupational fatality and injury rates, Hamalainen, Takala, and Saarela (2006) estimated that in 1998 there were 350,000 fatal workplace accidents (970 per day) and 264 million non-fatal accidents (724,000 per day) that involve at least three days absence from work. Estimates varied widely by global region, ranging from a fatality rate of 4.2 per 100,000 workers in the established market economies of Canada, the USA, the UK, Italy, etc., to 24.0 per 100,000 workers in Latin America and the Caribbean. Clearly, the burden associated with workplace injuries, as well as the harm associated with concomitant human pain and suffering, continues to exact an extraordinarily severe toll.

Despite recent downward trends (see Carayon et al. 2015), there is still an unacceptably high rate of workplace injuries. This has led an increasing number of safety researchers to argue that a fundamentally new paradigm is needed. There is a growing sense that traditional approaches (e.g. focus on tools and technologies, administrative controls, etc.) may be reaching the limits of their utility in terms of generating new and useful findings, and lack the contributions of a systems perspective. Simply put, the reductionist paradigm[1] in the study of workplace accidents, while providing important theoretical and practical value, has often diverted attention from the critical role played by organisational and other system factors. There is now a growing consensus that safety is an emergent property of sociotechnical processes within organisations and that further significant improvement in workplace safety will be reliant on progress in this area of research.

In the early 1950s, researchers at the Tavistock Institute in the UK began to assess the role of sociotechnical factors in the promotion of safe and effective work practices (e.g. Trist and Bamforth 1951). The term 'sociotechnical' was coined to

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describe the interactive influences of social and technological factors in determining the nature of work performed within an organisation and, to a large extent, the 'culture' of the organisation itself. As stated by Hollnagel: 'The idea of a sociotechnical system is that the conditions for successful organizational performance – and conversely also for unsuccessful performance – are created by the interaction between social and technical factors' (2009, 19).

In recent years, a number of areas have adopted an explicitly sociotechnical perspective. These include macroergonomics (Hendrick and Kleiner 2002), cognitive systems engineering (Hollnagel and Woods 1983), human-systems integration (Booher 2003), resilience engineering (Hollnagel, Woods, and Leveson 2006) and sociotechnical systems analysis (Coakes and Coakes 2009). Each of the above theoretical approaches seeks to shift the focus of safety research from a traditional reductionist approach towards a focus on the broader levels of social, ecological, organisational and technological factors that create and sustain functional (or dysfunctional) work systems and environments. In recognition of these approaches, the International Ergonomics Association has elaborated its definition of ergonomics to include organisational ergonomics, which is concerned with the optimisation of sociotechnical systems and their organisational structures, policies and processes. Many facets of the sociotechnical approach are included in this definition encompassing communication, work design, design of work teams, participatory design, organisational culture, virtual organisations and quality management.

To date, much of the emphasis in sociotechnical systems focused on complex or high-reliability organisations, with little or no attention given to industrial applications despite the potential relevance of the underlying approaches and methodologies. In light of the emerging interest in sociotechnical systems thinking to the study of workplace safety, a *Hopkinton Conference* was convened. The purpose of the conference was: (1) to identify critical gaps in our understanding of sociotechnical systems and their relation to workplace safety, and (2) to outline and propose future research aimed at addressing those gaps.

2. Hopkinton Conference on Sociotechnical Systems and Safety

On 18–19 October 2012, the Liberty Mutual Research Institute for Safety (LMRIS), located in Hopkinton, MA, USA, hosted a two-day conference entitled *Sociotechnical Systems and Safety*. The conference was organised by scientists at LMRIS, the Massachusetts Institute of Technology and the University of Wisconsin–Madison. An international group of 26 researchers in workplace safety, systems and industrial engineering, psychology, sociology, human factors, ergonomics and other disciplines was invited to participate, representing 20 institutions from Australia, Belgium, Brazil, Singapore, the UK and the USA. This *Hopkinton Conference* was the fifth in a series, each addressing an important area of concern for workplace safety, including injury epidemiology (Courtney et al. 1997), slips, trips and falls (Courtney et al. 2001), improving return-to-work research (Pransky et al. 2005) and fatigue and safety research (Noy et al. 2011). This symposium was expressly dedicated to providing a forum for theoretical cross-pollination among researchers with varying perspectives on sociotechnical systems thinking, with a principal focus on developing a research agenda ultimately geared towards the amelioration of workplace accidents and injuries.

In early 2012, participants were invited to the conference and were subsequently organised into issue-focused working groups. Five different working groups were formed, aligned with different topic areas as defined in advance by the organising committee. These topic areas included: (1) concepts, definitions and frameworks, (2) defining research methodologies for sociotechnical systems and safety, (3) modelling and simulation of sociotechnical systems, (4) communications and decision-making within sociotechnical systems, and (5) sociotechnical attributes of safe and unsafe organisations. The working groups, under the direction of a group-appointed chair, worked for several months to produce manuscripts for presentation, discussion and critique at the conference.

At the meeting in October 2012, each group presented their *work in progress*, followed by a critique from a separate working group that had been assigned to peer review the presenting group's draft manuscript. This was followed by an open discussion among all the conference participants focused on discussion of issues, limitations and recommended improvements. Following the conference, each working group incorporated comments and recommendations into a final manuscript that was subsequently reviewed by two or more external reviewers not associated with the conference. The collective output of this effort is presented in this special issue of *Ergonomics.*

3. Sociotechnical systems overview

Work is an inherently interactive and interdependent activity that is directly shaped by the sociotechnical context within which it occurs. A worker's network of work relations, comprising his or her co-workers, supervisors, customers, suppliers, etc., constitutes a *social* sub-system. Among the many critical aspects of the social sub-system are the reward and authority structures whose ubiquitous influences are felt across all organisational levels within work organisations (Munkvold 2000). Similarly, equipment and technologies (i.e. hardware and software) are generally required to perform work activities, and,

in many cases, a key objective of work is the production of additional artefacts. These are further influenced by the state of the art in the relevant technologies, global competitiveness and other factors. These technologies and artefacts, combined with the work processes and techniques that shape their use and production, comprise a *technology* sub-system that shapes work activities and directly impacts safety and productivity.

These work-centric social and technological sub-systems mutually enable and constrain one another in ways that largely determine the nature of work and, relatedly, the conditions and patterns of safety within which it occurs. For instance, elements of the social system can impact the technological system by means of decisions about which tools and equipment will be used at work, how, when and by whom they will be used. Similarly, elements of the technological sub-system impact the social sub-system, for instance, by constraining the selection of workers to those with specialised subsets of technological knowledge and skills.

Taken as a whole, a work-centric *sociotechnical* system encompasses a complex, dynamic network of interacting social and technological components that both enable and constrain work activities. Sociotechnical systems are examples of complex adaptive systems in that they comprise multiple interacting components whose emergent characteristics (i.e. productivity and safety) can be described as a non-linear function of their integrated activity (Miller and Page 2007). Sociotechnical systems are dynamic in that they continually evolve in response to multiple internal and external influences (Hancock 2009), including market forces, sociopolitical influences and technological innovations. Carayon et al. (2015) argue that sociotechnical systems are also 'open' in the sense that boundary regions between system levels are permeable, enabling the dissemination of control and communication across the system as a whole. This idea is picked up by Flach et al. (2015) in their examination of communication and decision-making within sociotechnical systems. These similarities to other complex adaptive systems, both natural and human-made, present the intriguing possibility that there may be potential benefit in applying the models and techniques currently used in their study to the domain of work-centric sociotechnical systems.

Sociotechnical systems thinking has proven to be a useful perspective on analysis and design within numerous domains including health care, transportation and military systems (Waterson et al. 2015), information technology (e.g. Harrison, Koppel, and Bar-Lev 2007) and organisational influences on innovation (Geels 2004). The purpose of the current *Hopkinton Conference* was to explore its potential extension to the area of workplace safety.

4. Issue areas in sociotechnical systems and safety research

The increasing number and variety of issues to which sociotechnical systems thinking is being applied, combined with investigators' divergent academic and professional backgrounds, has produced a significant amount of conceptual and semantic confusion. In the initial paper of this special issue, Carayon et al. (2015) address this problem through the development and elaboration of a sociotechnical model of workplace safety, paying particular attention to the generation of a common conceptual and semantic framework. The value of this effort lies in its potential to provide researchers and practitioners with a consistent conceptual structure within which to address systemic issues involved in workplace safety. The proposed model identifies key elements as well as levels of sociotechnical work systems that can affect safety.

Whereas Carayon et al. explore fundamental *conceptual* issues involved in the study of sociotechnical systems and workplace safety, the second paper addresses fundamental *methodological* issues. Waterson et al. (2015) approach the problem of identifying and/or developing rigorous yet non-reductionist methods by, first of all, delineating the 'roots' of sociotechnical methods in the 1950s. Thereafter, they describe methods associated with sociotechnically based theoretical approaches such as macroergonomics and cognitive systems engineering. Next, a collection of six case studies of sociotechnical systems in operation provides useful insights into the methods themselves as well as their associated advantages and disadvantages. Finally, an evaluation of the methods in terms of their ability to address theoretical and practical questions (e.g. the degree to which methods capture static/dynamic aspects of tasks and relevant interactions between system levels) is presented. The outcome of this evaluation highlights a set of gaps as they relate to the coverage and applicability of current methods for sociotechnical systems thinking and safety.

In the third paper, Hettinger et al. (2015) explore the requirements for, and potential applications of, sociotechnical system models for research as well as in support of the design of safe and productive work systems. They argue that sociotechnical system models serve at least two critical functions. First, they can offer crucial insights into detailed structural and dynamic characteristics of such systems which will become increasingly challenging as work environments continue to increase in overall complexity. System dynamic models and approaches consistent with 'soft system analysis' (e.g. Checkland 1999) are promising approaches towards this objective. Second, computational models to support empirical analysis of sociotechnical system properties and outcomes will be useful in the conduct of research that cannot realistically be conducted with existing organisations. Agent-based and discrete event modelling techniques are discussed as potential near-term tools for this work.

Flach et al. (2015), in the fourth paper, explore the underlying dynamics of two interrelated properties of sociotechnical systems with significant implications for workplace safety: communications and decision-making. Drawing on principles from General Systems Theory (von Bertalanffy 1969) and, in particular, Leveson's System Theoretic Accident Model and Processes approach (Leveson 2012), Flach et al. lay out a framework for understanding 'communicating' and 'deciding' as reflecting processes of *observability* and *controllability* across the multiple closed-loop components of complex sociotechnical systems. The authors elaborate on their conceptual framework by applying it to two case illustrations: a relatively complex sociotechnical system (a nuclear power plant) and a comparatively simpler system (a fast food restaurant).

The fifth paper, written by Kleiner et al. (2015), integrates issues and themes from the prior papers in a discussion of sociotechnical attributes of safe and unsafe systems. The problem, for example, of reliably and accurately identifying factors that allow some organisations to consistently perform at a safer level than their peers continues to be a major area of interest in the occupational safety literature. In this paper, the authors approach the problem from a sociotechnical perspective, with particular emphasis on viewpoints derived from the macroergonomics, human-systems integration and safety climate schools of thought.

Robertson et al. (2015), in the final paper, provide a summary of the major themes explored at the Conference both with respect to the papers produced for this special issue and the discussions held at the Conference itself. Chief among the latter were concerns with developing scientifically rigorous and practically useful approaches to sociotechnical systems analysis and design that are up to the task of encompassing the accelerating level of complexity in such systems. The clear desire to provide a sound scientific footing for safe systems design represents an enduring tradition in ergonomics and safety science, but the complex realities of contemporary and future work systems demand new approaches. The authors argue that success in such endeavours will ultimately be reliant upon well-conceived, multidisciplinary research initiatives, and they conclude their paper with suggestions regarding several potential approaches.

5. Conclusions

The impetus for this special issue of *Ergonomics* is the potential for convergence of a number of multidisciplinary perspectives on sociotechnical systems and workplace safety. There is a strong, shared commitment among the contributing authors to the following papers that a sociotechnical systems approach potentially affords the means to achieve sorely needed, significant improvements in the design and maintenance of safe working environments. The conference Organizing Committee sincerely hopes that the themes and issues identified and examined during the *Hopkinton Conference* will stimulate innovative and productive research leading to significantly enhanced workplace safety practices.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Note

1. Reductionist paradigms generally seek to trace phenomena such as workplace accidents and injuries to a single root cause. However, accidents within complex sociotechnical systems are more often a function of unforeseen or poorly understood interactions between system components.

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