Improving human control of hazards in industry

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Industrial accidents are still occurring at an unacceptable level. One way to reduce incidents is to better design industrial work systems so that humans can better recognise and manage hazards. In order to design work environments that support human’s ability to deliver safe and productive system performance, it is necessary to understand the humans, their work tasks, technology, organisational factors and external influences and how these have evolved and will continue to evolve over time. The aim of this study was to 1) gain insights into past, present and future work factors that affect human’s ability to safety manage industrial systems; 2) assess suitability of existing human factors and risk management methods to identify design improvement that would help humans deliver better system control and safety performance in industry both now and in the future. The study method involved conducting a review of literature to collect and collate information to identify important factors pertaining to the changing nature of human work in industrial contexts. The information from the literature review was then used to assess the benefits and limitations of current human factors and risk assessment techniques. The results of this study shows that the nature of human work, workers’ tasks, technology, organisational factors and external influences on industry have changed over time and will continue to change into the future. These changes can impact the way humans go about managing safety in hazardous industries. Most existing human factors and risk management techniques are limited in their ability to identify and manage contemporary human, technology, organisational interaction issues and opportunities. It is recommended that further work be done to develop techniques to suit the current and future industrial control scenarios.

Keywords: Safety; Human-centred industrial design; Human factors risk assessment;

1. INTRODUCTION

Industrial accidents are still occurring in hazardous industries. Examples of some of the major industrial accidents include major events such as Fukushima nuclear power plant meltdown, Lac-Mégantic train derailment, Soma mine disaster, Costa Concordia collision, West Texas fertilizer explosion and the crashes of Air Asia flight 8501, Malaysia Airlines flight MH370 and Germanwings flight . In Australia industrial accidents are resulting in an unacceptable number of worker deaths as shown in Table 1.

Table 1: Worker deaths in Australia’s Hazardous industries (Safe Work Australia, 2015)

<table>
<thead>
<tr>
<th>Hazardous Industry</th>
<th>Deaths in 2013</th>
<th>Deaths in 2014</th>
<th>Deaths – 2015 year-to-date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport, postal &amp; warehousing</td>
<td>51</td>
<td>49</td>
<td>8</td>
</tr>
<tr>
<td>Construction</td>
<td>17</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td>Mining</td>
<td>10</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>14</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>92</td>
<td>113</td>
<td>22</td>
</tr>
</tbody>
</table>
Incident investigations have repeatedly highlighted the significance of human involvement in the initiation and escalation of incidents (Baybutt, 2002; Cacciabue, 2000; Kletz, 2009; Stringfellow, 2010). One potential way to significantly improve the safety of hazardous industries is to design work environments that better support humans as they perform work and control hazards across different operating scenarios (Hollnagel, 2010; Rasmussen, 1988; Reason, 2008; Vicente, 2006; Woods, Dekker, Cook, Johannesen, & Sarter, 2010). Work systems comprise humans, technology, task, and organisational factors and they are also impacted by external influences as shown in Figure 1.

![Figure 1: Influence on human work (adapted from www.healthroundtable.org)](image)

In order to design work environments that support human’s ability to perform work and manage hazards it is necessary to understand the changing nature of the industrial environment, industrial organisations, technology, human tasks and human work preferences. It is also necessary to understand the strengths and limitations of existing human factors and risk assessment methods in highlighting the design changes needed to promote successful human control of hazards in current and future industry contexts.

2. AIM

The aim of this study was to 1) gain insights into past, present and future work factors that affect human’s ability to safety manage industrial systems; 2) assess suitability of existing human factors and risk management methods to identify design improvement that would help humans deliver better safety performance in industry both now and in the future.
3. METHOD
The study involved conducting a search of peer-reviewed literature available online from The University of Queensland’s (UQ) library website. The keyword phases used in the search started with “changing nature of” and “history of” and finished with “industry”, “the industrial environment”, “safety”; “industrial organisations”, “human factors”, “human work”, “industrial control”, “human work preferences”, and “automation”. Relevant articles found by the UQ search process were then reviewed and information pertinent to this study was extracted and collated to produce the representation of the changing nature of human work shown in the results section. The information from the literature review relating to current human factors and risk assessment techniques and overall system safety was also extracted and reviewed. Conclusions were then drawn about the future nature of human control in hazardous industries and the techniques required to assure successful and safe management of industrial hazards.

4. RESULTS
Over time, industrial systems have changed and the way their safety has been managed has changed. This change has been described in terms of “ages of safety” by Hale and Hovden (1998), Clarke et al. (2006), Borys et al. (2009), and Hollnagel (2011). Each age presents an additional and novel way to think about safety. In this article, a similar approach has been adopted which we term “eras of industrial control”. An overview of these “eras of industrial control” follow.

2.1 First era of industrial control – Localised, direct control
The first era of industrial control ran from the nineteenth century to after the Second World War. This era began with the introduction of electricity into industry. The industrial organisations of this era tended to be local separately-run companies that used local suppliers. The control of the operating processes also tended to be local and physical in nature. The operators where physically located within the process they managed. They manually interacted with levers, dials, and other controls to manage the process and their span of control was often constrained to what they could see and touch. The unreliably nature of the equipment often mean that operators had to manually intervene on a regular basis to keep production running. The constant interaction with the process led human controllers to develop good tactical knowledge and mental models of the fundamental operation of the process. However the constant manual intervention and pressure to keep production running resulted in unacceptable levels of fatigue and injuries. This led to the development of specialist boards and committees who were charged with improving both human well-being and productivity at work (Zionchenko & Munipov, 2005).

Scientific studies of safety were introduced and used to address technical causes of accidents and were aimed at guarding machinery, stopping explosions, and preventing structures collapsing (Hale & Hovden, 1998). Tools and techniques such as Failure Mode Effects Analysis (FMEA) and Hazard and Operability Studies (HAZOPs) were developed to help identify and address technical failures (Hollnagel, 2011). Scientific Management also emerged with the use of time and motion studies to determine the one
best way that workers could perform tasks efficiently and with minimal stress studies of human labour were also undertaken by the Scientific Management were introduced to improve labour (Hassall, Xiao, Sanderson, & Neal, 2015).

2.2 Second era of industrial control: Centralised control

After the war, military technology was transferred back into civilian industry. For example, during the World War II new technology, such as radar and sonar, led to the development of screen-based monitoring jobs (Chapanis, 1996). After World War II, this technology along with nuclear weapons technology was converted for civilian use. This lead to the development of large scale, complex work systems with centralised control rooms. Such industries often were managed by large corporations and they employed experienced people to run the operations. Examples include nuclear power plants and civil aviation systems. This transformation meant that human controllers were more isolated from directly interacting or being able to their senses to assess and control the systems. They were physically isolated from directly observing the system and had to rely more on instrumentation readings and alarm systems to diagnose and control system states.

This second era of industrial control overlaps the second age of safety, described as the “Age of Human Factors”, focused on solving safety problems by matching humans better to technology (Hale & Hovden, 1998). As technology became more complex, accidents were involving experienced people. Herbert Heinrich (1941) found that 88% of industrial accidents resulted from workers’ unsafe actions. For example experienced pilots were crashing planes. At the Three Mile Island nuclear power plant experienced operators failed to correctly interpret reactor status from the panel indications, and made control actions that worsened plant conditions (Booth, 1987). Further research has highlighted the importance of organisational human factors play in ensuring or undermining system safety. For example, the Columbia space shuttle accident was attributed to the interaction between a combination of technical factors, human factors failures, and organisational culture (Columbia Accident Investigation Board, 2003).

The scientists and engineers investigating how to prevent such incidents realised that instead of trying to change people to fit into the system, we should be designing the technology to fit people better (Shaver, 2009). This research lead to the establishment of the field of human factors and ergonomics (Shaver, 2009). Many human factors and organisational factors risk assessment techniques were developed during this period. Examples of human factors techniques include the TRACER method, Systematic Human Error Reduction and Prediction Approach (SHERPA), Human Error Template (HET), Task Analysis For Error Identification (TAFEI), Human Error HAZOP, Technique for Human Error Assessment (THEA), Human Error Assessment and Reduction Technique (HEART) and Cognitive Reliability Analysis Method (CREAM) (for more complete information see Stanton, Salmon, Walker, Baber, & Jenkins, 2005). Examples of organisational factors techniques include “Swiss Cheese” model (Reason, 2008), Accimap (Rasmussen & Svedung, 2000) and HFACs (Shappell & Wiegmann, 2000).
2.3 Third era of industrial control: Remote, collaborative control

Modern industry is currently adopting automation, autonomous technology, and they are on the verge of adopting cyber-physical systems (i.e. 3-D printing) and nano-technologies for wide ranging applications. The introduction of these technologies has removed human controllers further from the work face. Control rooms for automated and semi-automated technologies are being located hundreds of kilometres away from where the technology is actually working. For example, Rio Tinto has a control room in Perth that controls truck and rail movements in the Pilbara (Sato, 2011). Human control of autonomous technologies such as drones and robots can be the sole responsibility of coders and maintainers who are often separated in time and distance from the work done by the autonomous technologies. Human control in the third era of industrial control is shifting away from a supervisory control model more towards a collaborative or adaptive control model where humans and computers share and exchange control duties (Parasuraman & Wickens, 2008; Sheridan, 2002). The new technologies and forms of control have evolved in, and facilitated the growth of, global companies which now are heavily dependent of other companies like internet and satellite providers to ensure safe operations.

The third era of industrial control will also encompass a changing in the attributes of the people who will be employed by industry to control these new technologies. The next generation of workers are unlikely to have spent their childhood fixing motorised or powered machinery (e.g. radios, music players, motorbikes, or motorcars) as most of today’s technology is disposable or computerised which means that untrained “tinkering” can lead to catastrophic failures. For some there predominant experiences will come from electronic gaming and media. This change in experiential knowledge may impact on the ability of human controllers to understand operations at a fundamental level and the real-life impact or consequences that can occur.

The new technology, human factors issues and organisational management of controllers is interacting to produce “new” or emergent system responses that in turn can have significantly positive or negative impacts on human well-being and overall system performance. Previously mentioned approaches to safety and human factors have been based on learning from experience so that interventions can be identified and adopted that will prevent adverse events happening again in the future (Woods & Hollnagel, 2006). However, the changes associated with the third era of industrial control are likely to result in the emergence of new system responses for which there is no precedent.

To avoid catastrophic events in this third era of control, it is necessary to have approaches that can proactively identify ways to design system that help controllers successfully cope with complex, unexpected and even unimagined situations. Such approaches need to emphasise the importance of learning from and promoting successful performance as well as learning from and reducing unsuccessful performance (Borys et al., 2009). One area of research that may deliver benefits in this area is Resilience Engineering. Resilience Engineering aims to develop tools and techniques that allow an organisation to produce successful outcomes by anticipating and adapting to disturbances as well as continuing to recognise, learn from and protect against failures (Woods & Hollnagel, 2006). Two techniques are being developed using
Resilience Engineering principles. The first technique is Functional Resonance Analysis Method (FRAM: Hollnagel, 2012) which seeks to help analysis identify how normal variation within a system can lead to unexpected outcomes. The second technique is Strategies Analysis for Enhancing Resilience (SAfER: Hassall, Sanderson, & Cameron, 2014) which seeks to help analysis identify ways to improve system designs so human controllers can better manage industrial operations across both normal and abnormal situations.

The third era of industrial control will bring about significant paradigm shifts in the way work is performed, the nature of human-technology interactions, organisational designs and external governance required to manage the technical risks and social acceptance of risk associated with these industries. These paradigm shifts require commensurate changes in the way industrial risk and safety is assessed and managed. Current risk management initiatives tend to focus on technical performance or human performance or organisational performance as separate not interlinked phenomena. Current techniques also tend to focus on retrospective analysis of adverse events in order to avoid future reoccurrences. In addition, with the exception of FRAM and SAfER, there has been no significant innovation in risk management techniques in the last decade.

5. DISCUSSION
The literature review has revealed that there has been significant change to the working environment, organisational design, the type of control work done by humans and human preferences over the last 100 years. An illustrative summary of the changes is shown in Figure 2.

The literature review also revealed that current risk management initiatives tend to focus only on technical performance, or on human factors or on organisational performance. They also tend to focus on identifying ways to avoid adverse events. In addition over the last decade only two new, significantly different risk management techniques have been developed. This number is significantly less than previous decades.

Over the last decade there has been major changes to the working environment, the type of control work done by humans and organisational systems that own and operate hazardous industries. These shifts in operational control directly impact risk and safety in these industries. To prevent major catastrophes it is necessary to identify and manage risks – both the upsides and downsides - associated with these changes. Thus risk management techniques are needed that prospectively, retrospectively and wholistically look at the interdependencies and the performance that emerges from interactions between humans, technology, tasks, organisations and external influences (as shown in Figure 1). These new techniques also need to help designer create systems that enhance human performance and facilitate successful human-computer adaptive control in ways that deliver successful system safety and operational performance as well as improved human well-being.
Eras of industrial control

**Era 1:** Local, physical control
- Electro-mechanical systems
- Localised direct human control
- High number of highly experienced workers, working for small, usually locally-run isolated companies

**Era 2:** Centralised control
- Automated & Electronic/digital systems
- Centralised human supervisory control (increasing complexity and spans of control)
- Less workers working for larger, regional/international companies that share services

**Era 3:** Collaborative control
- Cyber-physical & autonomous systems
- Remote and collaborative control
- Workers with low levels of experiential learning working for global highly interconnected companies

Figure 2: Eras of industrial control
References


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