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Review

Applying a Human-Centred Process to Re-Design Equipment and Work Environments

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Abstract: Safe design is an increasingly influential approach due to a growing recognition of the contribution of design to workplace safety. It aims to eliminate workplace hazards by systematically involving end-users in the design or redesign process. In this review paper, the explicit and novel focus is upon redesign, rather than original design. The literature in the field is appraised and a human-centred safe redesign method is presented. The safe redesign method is a task-based, risk management approach that centres on end-users. In describing the method, indicative results from two domains are outlined: mining equipment and highway environments. Focusing on end-users and their tasks by means of a structured human-centred process can be highly beneficial. Further work to expand the human-centred safe redesign method is outlined.

Keywords: safe redesign; human-centred; industrial mobile equipment; safe highway design

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1. Introduction

1.1. The Importance of Design in Workplace Safety

There is now an emerging understanding of the importance of design in workplace safety [1]. This occupational insight has been a major motiving force in the growth of safe design of equipment and environments [2,3]. Examples of such design deficiencies in workplaces include visibility restrictions for operators of large industrial equipment [4], error-inducing tasks and procedures [5], or distracting roadway environments [6].

Focusing on work incidents, less than adequate design is a major contributory factor. For example, over half of plant-related incidents in Australia resulting in work fatalities had at least one design deficiency that contributed to the outcome [7]. An even greater involvement of the role of design in workplace fatalities involving machinery and fixed plant was later found, with 90% of such incidents attributed at least in part to design related issues [8].

In the construction industry, the importance of safe design was recently emphasised by Lingard *et al*. [9] who noted the high rates of fatalities and injuries in this domain compared to other comparable industries around the world. From this, they cited the emerging prominence of approaches that anticipate health and safety hazards in the early stages of construction projects [9]. In the mining industry, Horberry [3] examined the impact of design deficiencies on equipment operation and maintenance, he concluded that a large amount of incidents and avoidable downtime were partly due to equipment design inadequacies.

One approach to prevent or reduce the occurrence of such incidents is by means of ‘safe design’ (also sometimes referred to as ‘Safety in Design’ or ‘Prevention through Design’) [10]. This approach emphasises safety by original design to remove hazards and reduce risks [11]. It reduces the need for safety by procedure, other administrative controls, or trial and error [12].

Key aspects of safe design are the involvement of decision makers, employing a participatory design process that includes active involvement of end users and maintenance personnel, and the employment of risk management methods for the full lifecycle of the designed system, product or environment [2,3]. The safe design process produces design options to either eliminate hazards or minimise risks to those who make it, those who use or maintain it, and those in the vicinity of a workplace. It focuses on the peak of the hierarchy of control (e.g., hazard elimination) and, where possible, on the early stages in the design lifecycle [4].

1.2. Safe Design Legislation and Policy

Safe design provisions are now explicit in Australian Occupation Health and Safety legislation [1]. One of the seven action areas of the Australian Work Health and Safety Strategy 2012–2022 is ‘healthy and safe by design’ [13]. Across Europe, safe design is also a key focus of directives relating to construction (design and management) and machinery safety [14]. In the US, the ‘Prevention through Design’ program is now a long-term initiative to ‘design out’ workplace hazards as the most effective means of prevention of occupational injuries and fatalities [10].

Considerable costs are associated with unsafe design; for example, retrofitting, workers' compensation, environmental clean-up, and public liability [1]. Finally, as noted by Hale *et al.* [2], in some high-hazard industries, proof of safe design is becoming an obligation for equipment manufacturers to enter the market. Thus, safe design can be an effective process, although it is still not commonly used in domains, such as the minerals industry or highway design [4,6].

1.3. The Importance of Human-Centred Design

Unless human element considerations are considered in design then the work system may not work optimally [3]. Human-centred design is becoming an influential approach in the design of medical equipment, road vehicles and consumer products. It is a process that aims to make equipment and systems more usable by explicitly focusing on the end-user, their tasks and their work environment/use context. It requires that users and other stakeholders are involved throughout the system's design and development. A human-centred approach to safe design requires an understanding of the attitudes, abilities, limitations, motivations and expectations of users/maintainers and their tasks across the entire lifecycle of the work system [1].

Two key messages are that regular worker consultation is vital, and that using a structured process to undertake this consultation is extremely beneficial [1]. The fundamental tenet of this paper is that applying a participatory ergonomics-style approach to safe redesign processes would help create more human-centred systems. The key contributions of this review paper are an explicit focus on redesign (as opposed to original design), and a detailed presentation of a safe redesign method that draws upon findings from equipment and roadway redesign findings to describe the process.

2. Development of a Human-Centred Safe Design Process

The overall research objective was to develop, apply and disseminate a task-based, human-centred safe design approach. Until recently, there has been an absence of a standardised and widely-accepted overall safe design methodology. However, the American National Standards Institute (ANSI) 2011 Standard Z590.3 'Prevention through Design: Guidelines for Addressing Occupational Risks in Design and Redesign Processes' can help resolve this situation, particularly as it offers a broad framework for safe design [15]. The research method described below was aligned with the ANSI standard based on the philosophy that acquiring knowledge about actual users and work conditions of use are of key importance both to safe initial design and any subsequent re-design.

A challenge when designing for high-hazard work domains is that the certainty of the effects of design changes on safety of the actual equipment or current system of work is often not fully revealed until it is operational and the exact context of the working environment and work tasks are known [3,16]. Therefore, iteration and redesign are often of key importance. As noted by Burgess-Limerick [17,18], a risk-management framework is now frequently adopted to lead the application of human factors principles to workplace risks related to design. Such a process usually starts with understanding the broader context in which work activities take place. Thereafter, hazard identification and risk assessment are undertaken. Where the risk assessment requires that redesign is required, the risk control phase identifies and evaluates potential redesign control options.

These are then implemented, evaluated on a continuing basis and documented [18]. Within a participatory-ergonomics framework, the overall viewpoint is that obtaining end-user input can be vital to revealing design deficiencies and to identifying effective redesign solutions [3,17].

In the section below, a human centred safe redesign process is described: this is called the Safety in Design Ergonomics (SiDE) technique. The tool's methodology is described. When describing the stages, application examples and emerging findings from mining equipment and highway environments are given.

3. The SiDE Technique: Methodology and Indicative Results

A tool that is aligned with the ANSI standard and incorporates participatory ergonomics and risk assessment processes was initially developed and employed for equipment utilized in the minerals industry [18,19]. Being a task-based process, SiDE can help identify, comprehend and provide solutions to risks that users face when operating and maintaining equipment [3]. As will be noted below, its application demonstrated the importance of obtaining end-user input to reveal design deficiencies and to identify effective human-centred redesigns [3].

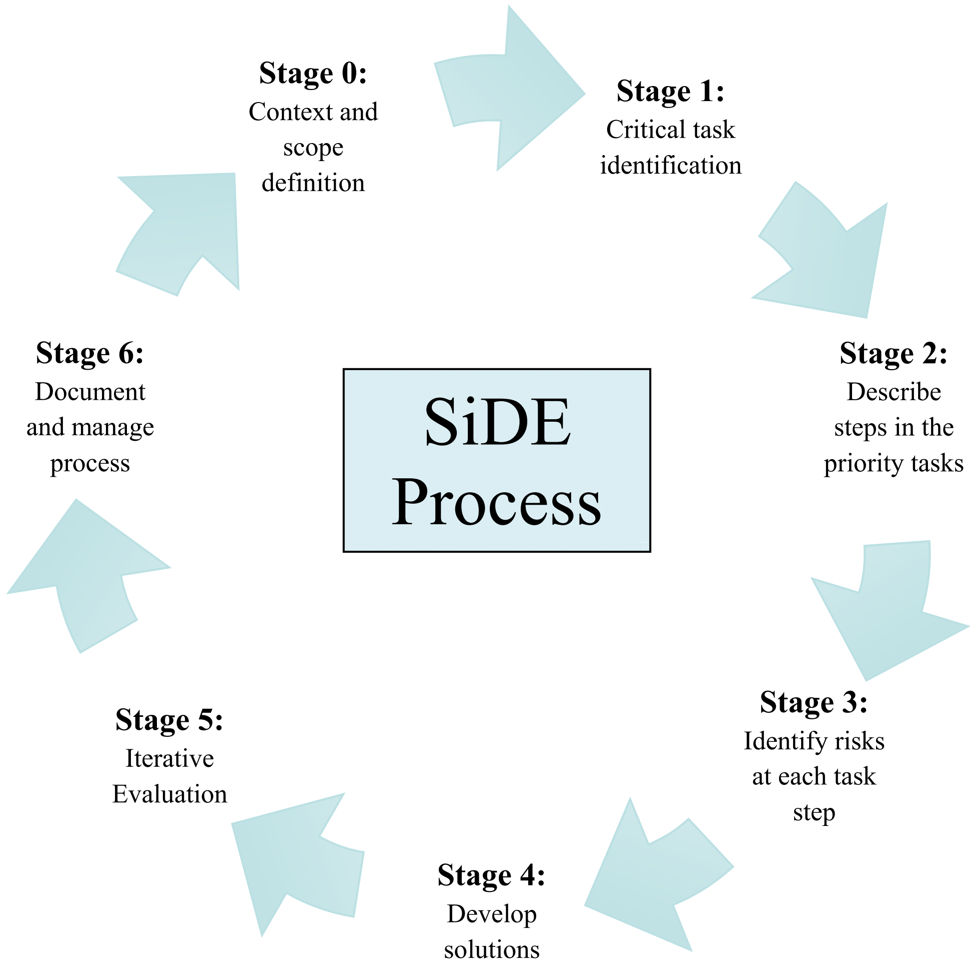

Figure 1. SiDE Methodology.

Regarding mine site equipment retrofits, SiDE could be utilized to examine site-specific risks related to new equipment, as a basis for new equipment purchase, to investigate equipment-related incidents, and to address residual risks during equipment operation or modification phases [18]. Such site-based use also allowed emergent interactions between the mining equipment and other aspects of the organisational system to be assessed after the equipment has been deployed [3]. Following Hale *et al.* [2], SiDE was developed based on the philosophy that acquiring knowledge about actual use and conditions of use are of key importance to safe redesign: this was especially critical in the minerals industry, where designers may be unable to visit mine sites to investigate equipment in use [19].

As will be seen below, the technique's methodology is capable of being modified to the workplace contexts outside of mining: for example, the safe design of highways. However, it usually involves seven stages, see Figure 1. Within this, stages 1–4 are usually performed in joint designer/end-user workshops [3].

Looking at these seven stages in more detail, Stage 0 defines the context and scope of the whole SiDE process. As the focus on this paper is upon redesign/refits, then the scope might therefore be examining an existing piece of equipment already in a workplace, or examining the work environment (eg the design of an existing highway). After this, the SiDE process context (including workshop location and amount of time available) is defined. As Horberry [3] noted, several days may be needed for the designer/end-user workshop.

After the scope and context are defined, Stage 1 identifies the critical tasks. For industrial equipment (e.g., in mining) a full list of maintenance and operational tasks performed may already exist. Similarly, for highway design, general driver task analyses do exist [20]. From these general task lists, critical tasks are prioritised. The exact process for this depends on the work domain being examined, but safety criteria such as previous risk assessments, hazards identified (e.g., energy), incidents and/or near misses would be used to help prioritise. Of course, in an ideal workshop, all tasks may be analysed; however, given the complexity of many workplaces, time restrictions often constraint the focus to tasks with highest priority risks.

Stage 2 involves decomposition of the high priority tasks identified in Stage 1. Essentially this is a hierarchical task analysis with characterisation of each task step and their order are described [21]. Of course, there is often a difference between 'tasks as designed' and 'tasks as actually performed' [3]. Therefore, task deviations, shortcuts or 'hidden' tasks should be identified and noted. Having a range of operators helps to clarify such task differences; equally, videos records of tasks being completed can often be a valuable task-analysis aid for this process [19].

Stage 3 involves identification of risks at each of the sub-tasks from Stage 2. Using easily understood risk-assessment matrices (e.g., 5-point severity and likelihood scales), risks are identified and any controls currently employed (e.g., warning signage for highway hazards) are noted. The task-based nature of the risk assessment assists in reducing the variance in risk perceptions of workshop attendees; nonetheless, as with other participatory/risk-assessment methods, different views still can a potential source of bias [3]. Again, a representative workshop sample, supplemented with videos of tasks being performed is beneficial.

Stage 4 is the development of human-centred solutions for the risks identified in Stage 3. Emphasis should be placed on development of design solutions towards the top of the hierarchy of control that aim to eliminate hazards. For example, Horberry, García-Fernández, Ventsislavova-Petrova, and Castro [22] examined highway design. They focused on the task of approaching an intersection, and decomposed this into seven subtasks. Risks were assessed and potential solutions proposed: a range of solutions were identified by drivers, with examples from the top of the hierarchy being 'remove the intersection entirely' or 'having grade separation' (e.g., an over-bridge). Lower level controls suggested included better warning signs/road markings, using red light camera or removing distracting stimuli (e.g., adverts) near the intersection [22].

Stage 5 involves iterative evaluation of the Step 4 solutions. Evaluation should be end-user focused. Incorporation of feedback may result in further development of solutions, which again are presented to end users for feedback. Focusing on the mine site equipment redesign aspects, the process resulted in many changes being made to mobile mining equipment, such as haul trucks and bulldozers. To date, this has included re-designing equipment access/egress points for operators: this has been a high priority area due to equipment access/egress being a frequent cause injury and sometimes death due to the cabin height of the vehicles [18,19]. Similarly, site based redesigns have occurred to improve ease of maintenance- for example the positioning of air filters to locations where maintenance personnel do not need to reach for them or hold awkward postures during filter changing so maintainers accessing them have a reduced risk of injury [19]. The use of the process for equipment procurement is also being investigated [18].

Throughout the entire SiDE process, and especially important at the end, Stage 6 involves managing and documenting. This documentation may include a risk register, who is responsible for which redesign aspect, and how would it be evaluated/reviewed. Again using the highway redesign example [22], a four column table of task, sub-tasks, risk and possible solutions was created. For each of the re-design options (e.g., improved road signs), further documentation could include a decision to make this signing change, who is responsible for it (including procuring and installing the sign) and whether an ongoing review of its effectiveness was to be performed.

4. Discussion and Conclusions

This review paper has presented the argument that there is often an explicit need for safe redesign in different workplaces. As such, this paper shows that the whole field should extend beyond safe original/initial design to also consider how equipment, tasks and environments can be safely modified after they have already been used. The research undertaken to date has shown that using the SiDE process may be beneficial in helping to redesign safer industrial equipment or highways environments. Of course, safe initial design is preferable, especially where system design can eliminate hazards rather than devising measures to control it. However, as many workplaces are complex, the emergent interactions between an item's design and other aspects of the socio-technical system cannot always be determined with precision a priori [3]. Hence, the continuing need for safe redesign and retrofits.

With a small amount of methodological alteration, the SiDE process can be adapted to make it suitable for the specific work domain being investigated. Further work with SiDE such as applying it to more complex cognitive tasks and providing additional support material (e.g., videos of tasks being performed) to remove possible bias from the actual end-users involved in the workshops are potential future research directions [19]. Equally, comparing the redesign solutions from a SiDE process to outcomes of existing techniques (e.g., HAZOP) or to the processes of other safe design researchers such as and De La Garza and Fadier [11] would be valuable. Finally, extra work to evaluate the success of the SiDE redesign outputs is needed, although initial verifications of the mining equipment redesigns have proven to be positive [19].

In conclusion, the participatory, task-based nature of SiDE makes it suitable for a wide variety of workplaces. In essence, focusing on end-users and their tasks, and applying an iterative human factors and structured risk management design process can help achieve safer redesigns.

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Authors' Contribution

Both authors contributed to the development of the safe re-design process for the minerals industry. Professor Horberry subsequently adapted the process for use in other domains. Both authors were actively involved in the writing of this paper.

Conflict of Interest

The authors declare no conflict of interest.

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