Health and Safety in Design

Core Body of Knowledge for the Generalist OHS Professional

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34.3

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The Risk Engineering Society actively contributes to the effective management of risks in the workplace and in the community by collecting and disseminating information on all aspects of risk engineering, organising technical meetings and conferences, and liaising with interested organisations. They place special focus on risk issues associated with construction, design, safe plant operation and management.

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Health and Safety in Design

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Core Body of Knowledge for the Generalist OHS Professional

Health and Safety in Design

Abstract
The concept of safe design or ‘prevention through design’ has developed in response to the recognition of the relationship between design and the risk of injury or ill health to ‘users’ of the designed product. Incorporating health and safety early in the design process is effective from prevention and financial perspectives. The generalist OHS professional should be a workplace advocate for healthy and safe design, encouraging critical thinking as part of the design process and, when appropriate, a coordinator of specialist expertise. Rather than considering design as a linear process, the OHS professional should identify design as a complex, multi-stakeholder, iterative process applying to the full life cycle of the designed product. Taking account of this complexity, this chapter discusses the design process and the implications for OHS practice, including relevant principles of safe design, and appends a design-process tool to guide the OHS professional in stimulating critical analysis of safety and health impacts.

Keywords
design, safe design, prevention through design, safety, health

Contextual reading
Readers should refer to 1 *Preliminaries* for a full list of chapters and authors and a synopsis of the OHS Body of Knowledge. Chapter 2, *Introduction* describes the background and development process while Chapter 3, *The OHS Professional* provides a context by describing the role and professional environment.

Terminology
Depending on the jurisdiction and the organisation, Australian terminology refers to ‘Occupational Health and Safety’ (OHS), ‘Occupational Safety and Health (OSH) or ‘Work Health and Safety’ (WHS). In line with international practice this publication uses OHS with the exception of specific reference to the Work Health and Safety (WHS) Act and related legislation.

Jurisdictional application
This chapter includes a short section referring to the Australian model work health and safety legislation. This is in line with the Australian national application of the *OHS Body of Knowledge*. Readers working in other legal jurisdictions should consider these references as examples and refer to the relevant legislation in their jurisdiction of operation.

On the morning of October 31, 2014, Virgin Galactic's SpaceShipTwo detached from its transport vehicle, WhiteKnightTwo, and commenced a test flight in the earth's atmosphere. SpaceshipTwo, a reusable suborbital rocket, was piloted by two very experienced individuals…

Just after detachment from WhiteKnightTwo, SpaceshipTwo fired its rocket. It increased speed, approaching the sound barrier. Suddenly it became aerodynamically unstable. Then it broke apart. Its pilot…along with his seat, was thrown from the vehicle…He suffered severe injuries [and] *the co-pilot died in the crash…*

The subsequent investigation determined that the 'feather' mechanism was activated at Mach 0.8 rather than Mach 1.4, creating increased drag on the vehicle, resulting in it losing aerodynamic stability and breaking apart.

The investigation explored several possible reasons for the pilots activating the feather system at the lower speed; however, the key question arising from the investigation was why did the designer/manufacturer not design in a fail-safe to ensure the feather system could not be activated at an unsafe speed? The reason given for this failure to include a fail-safe in the design was that the manufacturer "never envisaged that such qualified pilots would make such a mistake."

The investigation concluded that "the probable cause of this accident was [the designer/manufacturer's] failure to consider and protect against the possibility that a single human error could result in a catastrophic hazard…"

Brady, S. (2015). Human fallibility and automation: Lessons of the Virgin Galactic crash. *The Structural Engineer*, *93*(9), 30-32.

Table of contents

List of Figures

List of Tables

1 Introduction

The focus of the generalist OHS professional is the prevention of work-related fatality, injury, disease and ill health. The *OHS Body of Knowledge* chapter, 34.1 *Prevention and Intervention*, introduced the principles of control and the importance of hazard elimination or risk minimisation through design. Safe design as a control priority is highlighted in the *Australian Work Health and Safety Strategy 2012-2022*, where ‘healthy and safe by design’ is a key action area with the strategic outcome that, by 2022, “Structures, plant and substances are designed to eliminate or minimise hazards and risks before they are introduced into the workplace” (SWA, 2012, p. 9).

Generalist OHS professionals should be workplace advocates of safe design, influencing the design process and outcomes and, in complex or high-risk circumstances, working with human factors specialists and engineers. While access to specialist human factors and engineering advice is essential in safe design, generalist OHS professionals should have a working knowledge of ergonomic, human factors and engineering principles as they relate to the design of plant, tools and equipment and the workplace, and should be able to incorporate these principles into their practice. Also, they should have an understanding of the attitudes, abilities, limitations, motivations and expectations of users relevant to all components of the designed product across its life cycle (De la Garza & Fadier, 2005).

Fundamental to safe design is the systematic involvement of decision makers (including design specialists and management) and end-users, and the employment of hazard-analysis/risk-assessment methods for the designed product/system (ASCC, 2006). The rationale for such engagement is introduced in *Prevention and Intervention*, which discusses the concept of control in the context of a sociotechnical system with five levels of influence on OHS performance: system climate or environment; organisational and management structures, objectives and goals; communication and feedback processes; operator reliability; and engineering reliability.

This chapter complements and extends the *OHS Body of Knowledge* chapter, 34.2 *An Introduction to User-Centred Safe Design*,[1] which emphasises the importance of user-centred control and safe design within a framework of participatory ergonomics. Also, this chapter focuses on the multidisciplinary conceptual and technical knowledge that OHS professionals require to inform the design of plant, tools and equipment[2] as well as structures, which provide the context for use of such equipment. This chapter does not

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[1] *OHS BoK 34.2* An Introduction to User-Centred Safe Design (2019) is a revised edition of *OHS BoK* A User-Centred Safe Design Approach to Control (2014).

[2] See *OHS BoK 28 Mechanical Plant*.

address integrity of detailed engineering design or OHS design issues associated with design and construction of structures, which are considered specialist topics.[3] Also, it does not address the design of systems of work or the organisational and psychosocial aspects of work design.[4]

The chapter's first few sections briefly consider the impact of poor design of workplaces, tools and equipment; the evolution of human-centred design; and the duties of designers under the Australian harmonised legislation. Sections 5 and 6 focus on the importance of designing for people in complex sociotechnical systems and designing for the future, respectively. Section 7 examines key issues to be addressed at each stage of the design process, section 8 reviews the design role of professionals from various disciplines, and section 9 provides some examples of design failures that highlight the importance of safe design. Section 10, which focuses on implications for OHS practice, includes the key principles of safe design. The chapter concludes with a summary followed by an appendix of questions to guide OHS professionals in stimulating critical analysis of safety and health impacts during the design process.

1.1 Definitions

In the context of this chapter, design can be considered a staged, iterative process that involves multiple stakeholders and must take account of the complexity, flexibility and dynamic nature of sociotechnical systems where the human is the key element in the system (Lingard et al., 2014; Baxter & Sommerville, 2011). Lingard et al. (2014, p. 30) described design "as a dynamic, complex, and reflexive process of collective negotiations" (Lingard et al., 2014). The desired outcome is a design that:

- Considers the life cycle of a product
- Is desirable from a human perspective
- Is technologically feasible
- Is organisationally viable (IDEO.org, 2015).

Several disciplines and concepts relevant to discussion of safety in design are defined below.

Engineering design

The Institution of Engineers Australia (IEAust, now known as Engineers Australia) stated that "Engineering Design addresses issues of creating and delivering innovative, useful,

[3] For a review of the safe design approach in construction, see Lingard, Pirzedeh, Harley, Blismas and Wakefield (2014).

[4] See *OHS BoK* Design of Work (in planning at time of writing of this chapter).

reliable and economical technical solutions to meet human wants or needs," and defined the role of the engineer in terms of design:

> The major role of the engineer is the creation of national well being and security through the design and implementation of products, processes and technical systems of broad social utility. Design is the essential discipline of the engineer; it distinguishes engineering from science and mathematics, it is a fusion of creativity and technical discipline; it involves imagination, struggle and compromise. New technologies such as computer aided design have placed the design activity back on centre-stage within the profession. However there is much more to engineering design than technology, and it reaches far beyond the profession; it is a socially oriented activity. The need to conserve and recycle scarce resources and to safeguard our environment offers engineers a unique challenge to contribute to the achievement of sustainable socio-technical systems. (IEAust, n.d.a)

Ergonomics and human factors

The Human Factors and Ergonomics Society of Australia (HFESA, 2019) defined ergonomics and human factors as:

> …the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.
>
> Practitioners of ergonomics and ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people.

Safe design

The Australian Safety and Compensation Council (ASCC, 2006, p. 5) defined safe design as:

> …the integration of hazard identification and risk assessment methods early in the design process to eliminate or minimise the risks of injury throughout the life of the product being designed. It encompasses all design including facilities, hardware, systems, equipment, products, tooling,

Design thinking and human-centred design

While not focused specifically on safe design, the concepts and tools of design thinking and human-centred design differentiate them from the more traditional technical, expert-driven approach to design (Liedtka, 2014) and can provide an enhanced user-centred approach to design for the generalist OHS professional.

Design thinking has been defined as: "A human-centered innovation process that emphasizes observation, collaboration, fast learning, visualization of ideas, rapid concept prototyping, and concurrent business analysis" (Lockwood cited in Liedtka, 2014, p. 926). In design thinking the focus moves from the expert to collaboration with active participants, with

design being a more social process. Design thinking follows an iterative divergent-convergent process of:

- Exploration and data gathering to define the user needs and the problem
- Idea generation
- Prototyping and testing (Liedtka, 2014).

Read (2015) described human-centred design activity as focused on “understanding the needs and preferences of users, as well as their limitations, and designing to suit these,” and referenced the following principles:

- The design is based on an explicit understanding of users, tasks and environments.
- Users are involved throughout design and development.
- The design is driven and refined by user-centred evaluation.
- The design process is iterative.
- The design addresses the whole user experience.
- The design team includes multidisciplinary skills and perspectives.
(ISO 9241-2010:010 cited in Read, 2015, p. 128)

2 Extent of the problem

Several studies have established a clear link between unsafe design and work-related fatality and injury. A 2004 report – *The Role of Design Issues in Work-related Injuries in Australia 1997-2002* – by the then National Occupational Health and Safety Commission stated:

> The main finding from the study is that design continues to be a significant contributor to work-related serious injury in Australia. This is the case with a wide variety of machinery, plant and equipment, although the extent of involvement varies between them. Limitations of the data sources mean that the percentage involvement identified in this analysis are likely to be underestimates and to be imprecise.
>
> Most of the main design problems are old issues, with guarding the most prominent example. Other identified problems were poorly situated controls; inadequate interlock safety systems; absent or inadequate rollover protective structures and/or associated seat belts; inadequate fall protection; failed hydraulic lifting systems; and inadequate protection mechanisms (such as enclosed cabins) on mobile plant and vehicles. These appear to provide a lot of scope and opportunity for prevention activities. (NOHSC, 2004, p. 31)

A second report arising from the same study concluded that:

> Design issues are rarely considered comprehensively in OHS research…The analysis has shown that:
>
> - similar design problems are involved in many fatal accidents
> - design is an important contributor to fatal injury in many industries, and

- solutions already exist for most of the identified design problems (Driscoll, Harrison, Bradley & Newson, 2005, p. 33)

A decade later, a Safe Work Australia analysis of work-related fatalities occurring between 2006 and 2011 (SWA, 2014a) drew similar conclusions to the earlier study. It also noted that, while limited information and the subjective nature of the analysis created some uncertainty, “around 36% of in scope workplace deaths over the period 2006 to 2011 were definitely or possibly attributable to unsafe design of machinery, plant and powered tools” (SWA, 2014a, p. 26).

This problem is not limited to Australia. For example:

> Research in the United Kingdom (UK) indicates that approximately 64% of injuries sustained in the construction industry are attributable to poor design in one way or another…[F]ailure to design and implement physical safeguards caused 35% of fatalities and more than 20% of non-fatal maintenance incidents in the UK petrochemical industry. (Driscoll, et al., 2005, p. 2)

Also, poor design is responsible for many subtle and pervasive negative impacts on health and safety, and productivity. For example, Pheasant and Haslegrave (2006) found that the ideal height of the work surface for standing tasks in relation to the elbow height depended on the force required for the task, with higher rates of injury reported when the work surface was at an inappropriate height for the task.

Considerable financial costs are associated with unsafe design; for example, retrofitting, workers’ compensation, environmental clean-up and public liability (ASCC, 2006). If safety is incorporated at the design stage, such costs can be avoided. As Figure 1 shows, it is generally easier and cheaper to make safety improvements early in the product life cycle. This time-safety implementation curve – an accepted principle for many years – has been validated in research conducted by the RMIT Centre for Construction Health and Safety (Lingard et al., 2014).

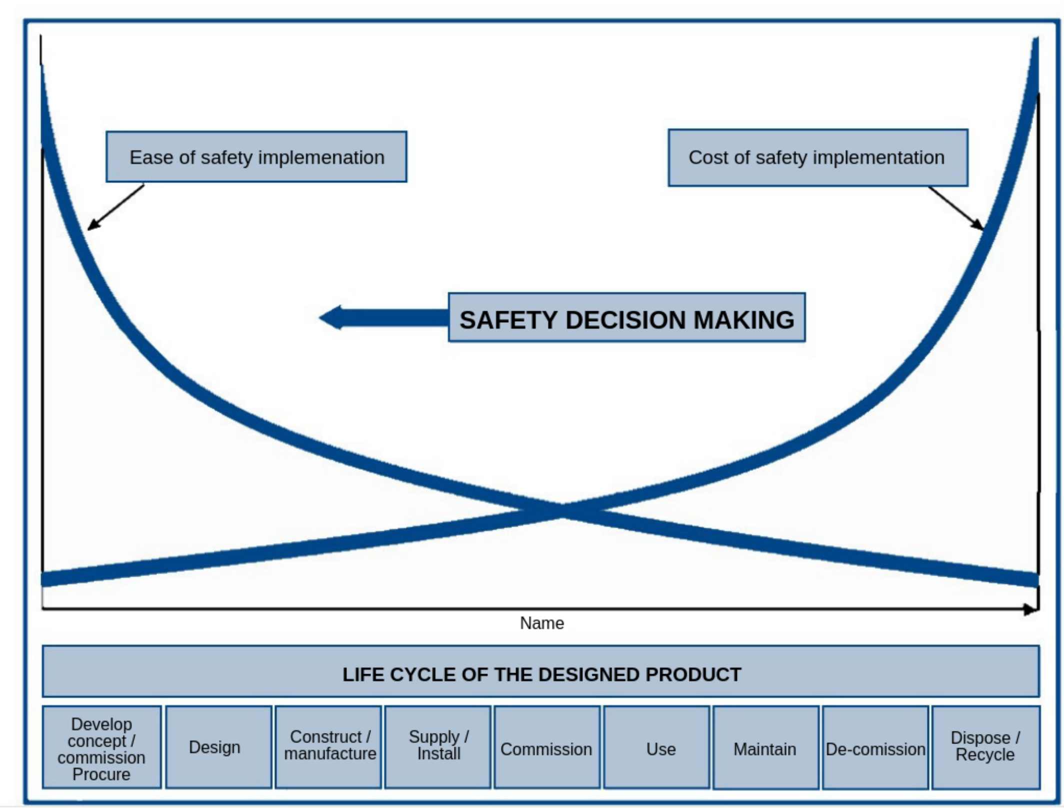

Figure 1: Cost benefits and the safe design process (modified from SWA, 2010)

3 Historical perspective

This section provides historical context for safety in design from the perspectives of engineering, ergonomics and human factors, safe design, design thinking and human-centred design. It can be seen that design has evolved from a technical process to one with the human as user at its core.

3.1 Engineering design

While engineering began with the building of ancient structures, modern engineering has its foundation in the Industrial Revolution of the 18th and 19th centuries. As engineering evolved, prescriptive standards were developed in response to failures in design that resulted in loss of life, injury and/or significant economic loss. With increasing complexity and developments such as computer-aided design (CAD) from the mid-20th century, many engineering codes and standards began to move from prescriptive- to performance-based requirements (see, for example, Carroll, Deighton-Smith, Silver & Walker, 2008; Hadjisophocleous & Bénichou, 2000). These changes enabled engineers to design to

performance requirements with the result that safety is increasingly in the hands of the professional engineer rather than constrained to referencing a table or chart.

It is notable that the IEAust's early definition of engineering design (section 1.1) did not specifically mention safety of people. In 2006, the ASCC, supported by Engineers Australia, produced an educational resource package – *Safe Design for Engineering Students* – to facilitate the embedding of safe design into the engineering curriculum (Creaser, 2008). Today in Australia, the role of the professional engineer in safety is espoused in the code of ethics and associated guidelines of Engineers Australia (2018, p. 3) within the sub-principle of 'Promote sustainability:' "Engage responsibly with the community and other stakeholders… [and] practise engineering to foster the health, safety and wellbeing of the community and the environment."

Modern engineering design practice is cooperative, rarely involving the input of only one engineer or one engineering discipline, and increasingly including professionals from other fields such as OHS, design, manufacturing, ergonomics and psychology. It is usually based around 3D CAD tools, which can visualise physical clashes of equipment, pipes, structures, cables, etc., and encroachment on areas such as walkways and work areas as well as interactions of people with the design environment or product. The use of 3D CAD has greatly enhanced the ability to assess human factors and safety during the detailed design process, and the process continues to evolve with applications of artificial intelligence and algorithm-driven design.

3.2 Ergonomics and human factors in design

Although ergonomics has evolved with the changing nature of work, it has always been a multidisciplinary profession, using expertise and research from several fields (e.g. engineering, psychology, architecture and biomechanics) to work collaboratively with users to improve the design of work and work environments.

In the early 1930s, the Royal Australian Navy and Air Force used the measurement of human characteristics such as coordination, concentration and reaction times to predict a pilot's ability to fly (Walker, 1961). "During the Second World War, as the incidence of human error grew with the increasing complexity of equipment used, the necessity of considering man's [sic] capacities and limitations as part of the design process was realized" (Berns, 1984, p. 277). This early application of ergonomics principles focused on the design of displays and controls.

Bullock (1999) noted that one of the first papers about ergonomics in Australia was written in 1953 by Dr John Lane (then the Australian Superintendent of Aviation Medicine). Titled 'Human Engineering: A new Technology,' Lane's paper explained that "human engineering aimed to determine human characteristics, to provide principles governing the design of machines for efficient human use, and to ensure an effective integration of man [sic] and machines for the accomplishment of an overall task" (Bullock, 1999, p. 24). Lane's passion for ergonomics was the trigger for broadening research in the aviation industry to consider, for example, clothing design, visual standards and noise.

In the late 1950s, the Australian Defence Scientific Service set up the Human Engineering Research Group (Bullock, 1999), which was the foundation of the Human Factors and Ergonomics Society of Australia (HFESA). The fundamentals of ergonomics began to be applied in other industries. For example, in 1967 Oxford surveyed school children to optimise the design of furniture in schools, and psychologists began to study "the relationship between environmental conditions, body temperature and the performance of skilled tasks" (Bullock, 1999, p. 25).

In 1964, a meeting of interested people from a range of disciplines formed the Ergonomics Society of Australia and New Zealand, and themes of presentations at annual conferences provide insight into the evolving scope of the profession:

- 1970s – workstation, tool and machine design in relation to posture and musculoskeletal injury
- 1980s – introduction of technology; computer-human interaction and the development of what was then called Repetitive Strain Injury (RSI)
- 1990s – application of organisational design and management; systems approach to ergonomics; product design; manual handling
- 2000s – workplace and job design; integrating the systems approach of ergonomics with a strategic approach to OHS management; participatory design
- 2010s – activity-based work; wellness and the impact of stress on workplace injury; occupational sedentary behaviour (Bullock, 1999).

Today the vision statement of the HFESA is "People-centred environments, products and systems for all" (HFESA, 2019).

3.3 Safe design

In the 1990s in Australia, safe design became a focus of the National Occupational Health and Safety Commission (NOHSC; from 2005, the ASCC) and, in 1998, NOHSC initiated the Safe Design Project that "focused on design-related aspects of plant, buildings, and structures, and materials and substances that impacted OHS" (Creaser, 2008). The outcomes of this project and related research elevated the importance of safe design to the extent that one of the five priorities of the *National OHS Strategy 2002-2012* was "eliminate

hazards at the design stage" (SWA cited in Creaser, 2008). In 2006, the ASCC developed a general model for safe design that gained widespread acceptance in Australia, with a definition of safe design (section 1.1) based on that employed by the US National Safety Council (Christensen & Manuele cited by ASCC, 2006). Previously, there had been little effort to define and standardise methods of safe design (Gambatese, 2008).

In 2007, the US National Institute for Occupational Safety and Health (NIOSH) launched a Prevention through Design (PtD) initiative "to achieve a cultural change so that designing out occupational hazards is the norm" (NIOSH, 2014, p. iii). In 2011, the American National Standards Institute published *ANSI/ASSE Z590.3 Prevention through design: Guidelines for addressing occupational hazards and risks in design and redesign processes*. This initiative, coordinated by NIOSH, provided an overall conceptual framework for safe design (ANSI, 2011).

3.4 Design thinking and human-centred design

'Design thinking' and 'human-centred design' have evolved as methods of placing human needs at the forefront of the innovation process (Gruber, De Leon, George & Thompson, 2015). Design thinking has its roots in the 1960 publication of Marples' *The Decisions of Engineering Design* and the multidisciplinary approaches to creativity and engineering design that followed and in turn influenced early approaches to human-centred design for problem solving in science and technology (see Cross, Dorst & Roozenburg, 1992). In 1991, an influential 'Research in Design Thinking' workshop with international delegates was held at Delft University of Technology in The Netherlands (Cross et al., 1992). Also in that year, three industrial design companies (David Kelley Design, ID Two and Matrix Product Design) merged to form IDEO Inc., which has been largely responsible for popularising the concepts of design thinking and human-centred design (Szczepanska, 2017).

Human-centred design evolved from intersections between ergonomics and such fields as computer science and artificial intelligence (Giacomin, 2012). Focused on understanding behaviour, human-centred design has, for example, applied neuroscience to the design of websites and other technology interfaces to optimise user engagement (see, for example, vom Brocke, Riedl & Léger, 2013). To date, such consideration of visual cues, mental models and other brain-driven reactions has had little impact on the design of plant, tools and equipment.

4 Legislation and standards

Today codes and standards struggle to keep pace with technological change and scientific advancement. As noted in section 3.1, many requirements in engineering design codes and standards are now performance-based, giving designers more scope for innovation in producing products that serve society more effectively.

Toward the end of the 20th century, the concept of ‘equivalent safety’ was introduced into some design codes (see, for example, Hadjisophocleous & Bénichou, 2000), allowing for more design by analysis. For example, the Building Code of Australia moved to performance-based requirements that encourage the use of innovation in fire safe design of structures. This has permitted innovative structural designs to be practicable. It would not have been possible to protect some modern buildings with code-based designs (e.g. tunnels and high atriums).

With the advent of the concept of equivalent safety, the designer has had to consider the user, and how the design interacts with humans and how humans interact with the design. Legislation has moved to deal with this by focusing on making the workplace safe so far as is reasonably practicable (SFAIRP). This approach is reflected in the Australian national model legislation, which requires that: “The designer must ensure, so far as is reasonably practicable, that the plant…or structure is designed to be without risks to the health and safety of persons…” (SWA, 2016 s. 22).

The application of SFAIRP in design was demonstrated in the case of *Slivac v Lurgi 2001* (that involved a designer), where it was concluded that, " ... to determine reasonably practicable it is necessary to balance the likelihood of the risk occurring against the cost, time and trouble necessary to avert the risk" (Creighton & Rosen, 2007, pp. 76-77).

Design includes re-design or modifications to a design and a designer is a person who conducts a business or undertaking that designs plant or structure “that is to be used, or could reasonably be expected to be used, as, or at, a workplace” (SWA, 2016 s. 22). Designers include people who:

- Prepare sketches, plans, draws or models including prototypes
- Make decisions for incorporation into design
- Change design during manufacture
- Change existing plant so that new measures for controlling risk are required (SWA, 2014b).

The people whose health and safety must be considered include those:

(a) who, at a workplace, use the plant…or structure for a purpose for which it was designed; or

(b) …;[5] or
(c) who store the plant…at a workplace; or
(d) who construct the structure at a workplace; or
(e) who carry out any reasonably foreseeable activity at a workplace in relation to:
    (i) the manufacture, assembly or use of the plant for a purpose for which it was designed, or the proper storage, decommissioning, dismantling or disposal of the plant; or
    (ii) …; or
    (iii) the manufacture, assembly or use of the structure for a purpose for which it was designed or the proper demolition or disposal of the structure; or
(f) who are at or in the vicinity of a workplace and who are exposed to the plant…or structure… (SWA, 2016, s. 22).

In order to meet this broad range of duties, the designer must ensure that necessary calculations, analysis, testing and examination are undertaken in relation to the plant or structure. Adequate information in relation to each purpose for which the plant or structure was designed must be provided to the relevant person, including the manufacturer and user of the plant or structure.

The legislation recognises that plant and equipment may be purchased from a supplier rather than designed in-house. It may be imported, either through a supplier or directly by a company. In such cases, the importer and/or supplier (including the company that may be a direct importer) carry many of the obligations of the 'designer.'

The importer/supplier must:

(3) (a) carry out, or arrange the carrying out of, any calculations, analysis, testing or examination that may be necessary for the performance of the duty [of ensuring so far as is reasonably practicable that the plant…or structure is without risk to health and safety of persons]; or
    (b) ensure that the calculations, analysis, testing or examination have been carried out.
(4) …give adequate information to each person to whom the [importer/supplier] [provides/supplies] the plant…or structure concerning:
    (a) each purpose for which the plant…or structure was designed or manufactured; and
    (b) the results of any calculations, analysis, testing or examination…; and
    (c) any conditions necessary to ensure that the plant…or structure is without risks to health and safety when used for a purpose for which it was designed or manufactured [including any reasonably foreseeable activity in relation to assembly or use of the plant/structure for a purpose for which it was designed or manufactured or the proper storage, decommissioning, dismantling or disposal of the plant/structure] (SWA, 2016, ss. 24, 25).

In addition to providing information, the person conducting a business or undertaking has a duty to consult their workers who will be using the plant or structure:

[5] Legislation also refers to "substances," which are not within the scope of this chapter.

> The person conducting a business undertaking must, so far as is reasonably practicable, consult...with workers who carry out work for the business or undertaking who are, or are likely to be, directly affected by a matter relating to work health and safety (SWA, 2016, s. 47).

In order to meet this obligation, there is an expectation that when an employer engages a designer arrangements are made for consultation with the relevant workers.

In addition to providing information on the design and consulting with users as per the legislative requirement, designers (and purchasers) should demonstrate and document the due diligence of the design process that ensures that the safety of the users has been addressed. Assessment and documentation of the due diligence, and the involvement of specialists, will be proportional to the complexity of the design and the level of risk. In complex plant design, due diligence may be demonstrated through a safety case documentation while a report attached to design drawings may suffice in less complex situations.

5 Human variability in complex sociotechnical systems

The ergonomics principle of designing for the user is well established and underpins all discussion on safe design (ASCC, 2006). However, the concept of the 'user' is often limited to the end user. To be effective, safe design must encompass all the 'users' who construct/manufacture, commission, operate, maintain or demolish/dispose the designed product. Designing for this range of users requires a broad view of 'use.'

Many designs are based on what the designers think about how the work occurs and how the designed product will be used (often referred to as 'work-as-imagined') (Hollnagel, Wears & Braithwaite, 2015). However, work activities and how people carry out work tasks will vary as people adjust to current conditions; in fact, such variability may be vital for success. This variation may be conscious or unconscious, and may not always seem rational. Rather than talking about error (which has the connotation of mistakes or blame), it is more useful to refer to 'human performance variability.' While degrees of variability and flexibility are normal and necessary in sociotechnical systems, they can also lead to undesired outcomes (Hollnagel et al., 2015).

The concept of 'error-tolerant' design has been employed to make things 'resilient to human error,' (Asfahl, 1999), implying that the design must be tolerant of misuse. A more useful interpretation is that the designed product should be tolerant of variability in use or

operation. A corollary of such tolerant design is that the design ‘fails-safe’ or ‘fails to safety.’ Thus, should variability in use or operation of a designed product be beyond the design parameters, the product remains in a safe condition. Fail-safe should be a foundation principle in any design and should encompass three elements:

- General fail-safe – in event of failure of one of its components, the product is in a safe mode
- Fail-safe redundancy – safety of a system, subsystem or components is preserved by alternate parallel or standby units
- Fail-safe in worst case – the design considers the worst situation to which it may be subjected in use (Asfahl, 1999).

The remainder of this section considers human variability from two perspectives: variability across individuals (physical and intellectual), and variability within individuals across time (physiological, psychological, social, contextual and compensatory). While the factors discussed here focus on the workplace, designers and OHS professionals should be mindful of the impact of physical and psychological health, including drugs and alcohol, on individual variability across time.

Variability across individuals

- *Physical:* Differences in human body scale (body dimensions, strength, reach)

  The ability for individuals to safely undertake their work will be dependent on what they can safely see and touch. Anthropometric dimensions of the human body are quantitative measures used to optimise the design of products to suit the size range of the user population. Because, for example, some people have long torsos and short legs whilst the opposite is the case for others, static anthropometry based on body height is not an adequate basis to ensure safe design. Functional anthropometry based on the actual movement and shape of the body is more appropriate to use in design development. Three-dimensional anthropometry devices are now available that enable the whole body to be scanned. Data from population studies using these methods are available in databases such as WEAR (Work Engineering Anthropometric Resource). While some countries (including Korea, USA and The Netherlands) have sizing surveys that support safer and more effective design, there is currently no Australian database with an acceptable sample of subjects (Veitch et al., 2013). Consideration of physical variability is of increasing importance with the broadening in diversity of the workforce.

- *Intellectual*: The ability to reflectively integrate education, training and experience to develop competence in a task or job varies across people in a range of complex ways.

Variability within individuals across time

- *Physiological*: Perception, fatigue, boredom,

  A worker's perception skills can impact their safety at work (e.g. the perception of different colours may vary, particularly for those with colour or other visual abnormalities). For optimised work performance, individuals require the cognitive capacity to make correct decisions and assess inputs from the work environment (see, for example, Taylor, Watkins, Marshall, Dascombe & Foster, 2015). If the worker is fatigued, their reaction time and decision-making capacity can be negatively impacted. This is relevant for shift workers where the circadian rhythm is disrupted as a result of changing sleeping patterns, and also applies to workers who do not receive sufficient sleep to optimise their cognitive capacities (see, for example, Gibbs, Hampton, Morgan & Arendt, 2005).[6]

  The design of some jobs (particularly those with repetitive tasks such as assembly line work, goods processing or inspection) can become cognitively and physically fatiguing, and boredom can increase the risk of error. Research on cognitive arousal and performance indicates that prolonged periods of under-arousal such as boring jobs and over-arousal such as highly stressful jobs, increase the potential error and hence OHS risk (Grandjean, 1997).

- *Psychological*: Desire to improve, innovate, balance efficiency and thoroughness

  Hollnagel (2009, p. 15) explains the efficiency-thoroughness trade-off (ETTO) principle:

  > In their daily activities, at work or at leisure, people (and organisations) routinely make a choice between being effective and being thorough, since it rarely is possible to be both at the same time. If demands for productivity or performance are high, thoroughness is reduced until the productivity goals are met. If demands for safety are high, efficiency is reduced until the safety goals are met.

  Drive for autonomy and control

  Workers trained on a job will develop their own ways of completing tasks that, to them, seem safe and efficient. Workers react against being treated like robots with totally prescribed movements and short-cycle work patterns. By enabling some autonomy in how a job is done within the boundaries of safe work methods, individual difference (e.g. left-handed workers, ageing workers, those with colour vision abnormalities and those with specific physical needs) can be accommodated in the workplace. Also, workers respond positively when they consider that they have some control over the work. (WorkCover NSW, 2014)

[6] See *OHS BoK* 20 Fatigue.

- *Social*: Meeting expectations of others, work pace or work standards

  Set performance outcomes or key performance indicators (e.g. production outputs per hour or shift, or optimising the use of a machine by minimising down time for jobs), can drive workers to focus on achieving these performance standards at the risk of health and safety. A worker focusing on meeting workload expectations may resort to taking short cuts (e.g. attempting to use manual force rather than a manual-handling lifting aid to complete a task, or not isolating a machine before clearing a jam).

- *Contextual*: Environmental factors such as noise, humidity and temperature

  The physical work environment can impact directly on the risk of injury. For example, exposing workers to extremes of heat or cold in the workplace not only presents a direct risk of heat-related illness, but also increases the risk of physical injury such as lacerations and amputations (Xiang, 2014). Noise is also known to impact work performance (e.g. Errett, Bowden, Choiniere & Wang, 2006; Nassiri, et al., 2013). The presence of multiple cognitive inputs in the workplace such as high workload demands or distracting conversations, increases the likelihood of a perception of a lack of control. This can result in workers missing important cues and increasing the risk of injuries.

  Technology

  Technology is ubiquitous in the workplace as a core system or work platform, or as an interface with other systems or equipment. Not only do the visual and spatial aspects of technology interfaces impact human perception and so behaviour and decision-making, but also the mere presence of the systems can impact human behavior. For example, digital communication systems have led to the 'always on' employee who experiences increased cognitive load without natural rest breaks, which can lead to diminished performance; concomitantly, information overload through technology can result in choice overload that can compromise decision making (Joyce, Fisher, Guszcza & Hogan, 2018). The challenge is to maximise the positive, enabling aspects of technology while minimising the negative, oppressive effects (Cascio & Montealegre, 2016).

- *Compensatory*: Variations in raw materials, missing or inappropriate tools

  Safe systems of work make assumptions about the presence of raw materials that are in specification and that engineering systems operate as designed. If these assumptions are not upheld, it is likely that workers will take action to 'compensate' for these deficiencies. Thus, while a design may take account of regulations, standards and procedures, it must also be suitable for a complex environment where the conditions and methods of use will vary ('work-as-done').

6 Design for the future

Design is inherently about the future. As indicated in section 1.1, design must consider feasibility, variability and desirability for users while taking into account the complex, dynamic nature of sociotechnical systems. Design must address changing parameters that might apply throughout the product life cycle, which may be many years, with some products creating legacy issues that endure for decades (e.g. objects containing asbestos). In designing for the future, it should be recognised that accepted standards for health and safety change over time. What is accepted as 'healthy' or 'safe' today may not meet community standards in five years' time.

The future of work is a current topic of interest with a number of agencies preparing 'vision' reports (e.g. PwC, 2014, 2018; CEDA, 2015; Hajkowicz et al., 2016; EY, 2018; Horton, Cameron, Devaraj, Hanson & Hajkowicz, 2018). While future scenarios may vary in these reports, a common theme is that:

> Tremendous forces are radically reshaping the world of work. … Disruptive innovations, radical thinking, new business models and resource scarcity are impacting every sector. …[T]he scale of change is not unprecedented. However, what is unique is the pervasive nature of the change and its accelerating pace. (PwC, 2014, p. 6.)

Awareness of likely changes to the nature of work is a vital input to the design process.

The remainder of this section considers the future of work from a design-relevant perspective under four headings: technology, people, place and organisation of work. These four factors interact to determine the modes of information sharing and communication, and the nature of work relationships. Figure 2 shows the interaction of these factors as they inform design.

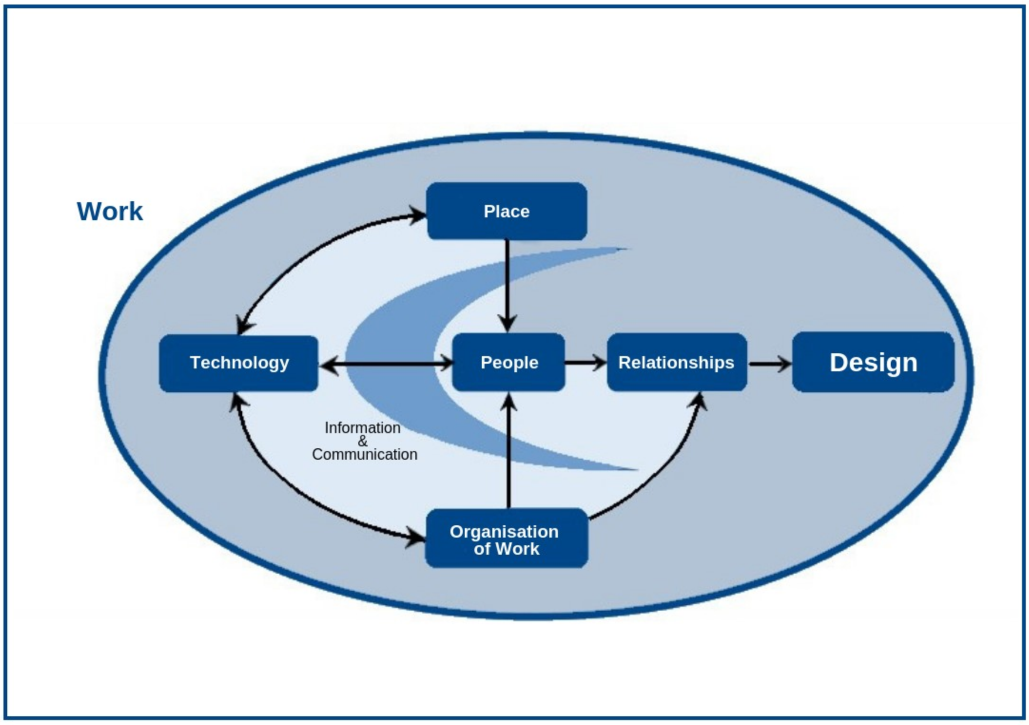

Figure 2: Interaction of place, technology, organisation of work and people as a basis for thinking about the future of work and design

Technology

Technology is seen as the driver of most of the change currently being experienced as well as changes expected in the near future (CEDA, 2015). “Exponential and/or steep growth in computing power, device connectivity, data volumes and artificial intelligence [means] many existing jobs are likely to be automated and many new jobs to be created” (Hajkowicz et al., 2016, p. 7). Although automation, robotics and artificial intelligence are likely to have greater impact on jobs with tasks that are routine, repetitive and rules-based, and those with low levels of social interaction, creativity, mobility and dexterity (Hajkowicz et al., 2016; CEDA, 2015), every level of an organisation and its people will be affected by them (PwC, 2018). “Increased use of automated systems is raising the complexity of tasks and requiring higher skills for entry-level positions” (Hajkowicz et al., 2016, p. 10).

People

Technology together with other forces such as migration are changing the Australian workforce (CEDA, 2015). “Over the last 50 years, there have been large changes in the skill composition of employment, with consistent growth in employment of high-skill workers, a large decline in the share of middle-skill workers and a smaller decline in low-skill workers [due to] the introduction of information and communication technologies” (CEDA, 2015, p. 11). Factors such as the ageing population, cultural diversification and retirement pressures are also changing the demographic structure of the workforce (Hajkowicz et al., 2016), as is

the increasing participation of women in previously male-dominated occupations. The expectations of young people entering the workforce are relevant:

> They are connected, technologically advanced, creative and entrepreneurial, and have new perspectives on desirable work environments, ethical issues and communication styles. (Hajkowicz et al., 2016, p. 10).

Place

The 'workplace' is changing at both a macro and micro level. Australian workplaces are moving from a focus on the resource sector to services, knowledge and innovation (Hajkowicz et al., 2016). At the more micro level, the workplace is being directly impacted by the introduction of technology for specific tasks as well as the concept of a workplace expanding to include remote work, work from home and 'hot desking.'

Organisation of work

Organisation of work is also changing. The creation of the entrepreneurial peer-to-peer marketplace and the increasing number of small businesses are changing business and employment models (Hajkowicz et al., 2016). The technological capacity for continual connectivity is changing the concept of normal working hours with many reports of increased availability of workers expected by employers/clients (Hajkowicz et al., 2016).

7 The design process

The life-cycle approach to design (see SWA, 2018) is vital as there is often the erroneous assumption that designing for safety in one stage of the life cycle of the designed product will naturally and inevitably reduce risks in all stages. For example, designing for supermarkets to integrate the delivery and display of products from supply chains needs to consider workers at both ends of the supply chain and at all points in between, including reducing manual handling of goods by packing fresh food at the farms in containers suitable for transport and shelf-display, and food manufacturers packing dry goods in display-ready cartons that eliminate the need for store staff to unpack items individually.

Design processes for sociotechnical systems have three key requirements:

- Engagement of people in the design process
- Analysis of the system within which the designed product will be used by a human
- A controlled sequence of decision making to develop and implement the design.

This section considers these three requirements in the context of design stages, consultation and system analysis.

7.1 Design stages

While in practice the design process is iterative, flexible and dynamic, the traditional technical approach tends to consider design in three phases: concept development, feasibility assessment and definition of the design. Design thinking (section 3.4) describes additional stages that can be correlated with the technical approach (Table 1). While design thinking does not address health and safety, it is human-centred and so emphasises the 'human' focus, which is an essential part of safe design.

Table 1: Comparison of design stages as described for technical and design thinking approaches

Technical approach	Design thinking (Plattner, 2017)
Concept development	Assume that the answer is not known
	Empathise
	Define
	Ideate
Feasibility assessment	Prototype
	Test
Design definition	(Definition)

A key difference between the two approaches is that design thinking stages are characterised by what IDEO.org (2015) describes as the seven mindsets:

Empathy – understanding others, and keeping their physical and psychosocial needs within the context of the design

Optimism – embracing possibilities; focusing on opportunities rather than inevitable constraints

Iteration – valuing feedback and opportunities to refine and improve

Creative confidence – trusting in the human-centred process and people to be able to come up with a solution; accepting that intuition can play a role

Making it – turning abstracts into tangibles so ideas can be tested for feasibility

Embracing ambiguity – accepting that the answer may not be known at the start; pursuing different ideas, and discarding those not likely to work

Learning from failure – accepting that failure is a powerful learning tool.

These mindsets may be present to varying extents in the technical designer, but it is their overt presence that is seen to set design thinking apart as a process.

7.2 Consultation and engagement

Consultation with users and others who may be impacted during the life cycle of the designed product is not only a legislative requirement (section 4), but also essential for the effective and safe use of the product. This consultation must occur at each stage of the design process from concept development through to design definition, and include feedback once the design has been constructed and used. The design tool in Appendix 1 provides examples of questions to ask and issues to explore as part of the consultation and engagement with users and others.

While OHS and design professionals may recognise the importance of involving users in the design process, they also must be aware that user input may be hindered by a lack of understanding or familiarity with design documentation such as written specifications or plans. Drawing on Broberg, Andersen and Seim's (2011) discussion of participation in design processes, effective user engagement in design requires:

- The designer and users to have a shared understanding of the way in which the designed product will be used and the context in which it will be used
- The users to have a method of clarifying and articulating their concerns and wishes
- An aid to joint problem solving that supports design collaboration rather than negotiation.

The use of 'objects' (e.g. workbooks, photographs, scale models, virtual reality and computer-generated images) can facilitate such engagement; however, to be effective these objects should be:

- Particular to the design under discussion
- Responsive to the discussion and so can be manipulated to support discussion and shared understanding
- Supported by facilitated and structured use
- Used as part of a learning event (e.g. a workshop) (Broberg et al., 2011).

7.3 System analysis

Previous sections have highlighted the importance of including all potential users in the design process; however, this should be within a structured analytical framework. A range of such analytical processes forms the basis of ergonomic approaches to design. This section introduces the cognitive work analysis (CWA) framework, 'PETE' analysis, misconception analysis and work system analysis.

7.3.1 Cognitive work analysis

Read (2015, p. 371) described the cognitive work analysis (CWA) framework as a "formative, constraint-based approach in that it models the possibilities for behaviour within the constraints imposed by the system" with the key being the *possibilities for behaviour* rather than a focus on actual or normative behaviour. The CWA framework has five phases of analysis:

- Work domain analysis (WDA)
- Control task analysis (ConTA)
- Strategies analysis (SA)
- Social organisation and cooperation analysis (SOCA)
- Worker competencies analysis (WCA) (Read, 2015).

Read (2015) demonstrated the capacity for CWA to support the design of a complex sociotechnical system by applying it to pedestrian use of rail level crossings and developed an extensive toolkit for CWA application. The toolkit, which adopts a human-centred design approach, addresses design as an 11-step process with guidance, worksheets, examples and discussion prompts for each stage, and references for further reading. OHS professionals involved in design of a highly complex nature or whose main role is related to design are encouraged to review the toolkit for applicability to their work. Those with little or no experience in CWA should read 'The CWA Design Toolkit' in conjunction with the recommended further reading (Read, 2015).

7.3.2 PETE analysis

One of the contributors to this chapter, Fiona Begg, whose OHS practice includes facilitation of integration of OHS into design, proposed a simpler approach to system analysis as part of design. The PETE analysis addresses the system components of people, equipment, tasks and environment:

> ***P**eople* likely to be in the work area, who may engage directly or indirectly or be impacted by the design, including operators, maintenance, other workers, contractors and visitors.
>
> ***E**quipment* including the designed product, ancillary equipment, interfaces, storage requirements, equipment required for commissioning, maintenance and decommissioning of the designed object.
>
> ***T**asks* that will be undertaken in manufacture/construction, commissioning, operating, maintaining, decommissioning and disposing of the designed product with consideration given to physical, cognitive and psychosocial aspects of the tasks.
>
> ***E**nvironment* – physical and psychosocial aspects of the environment within which the designed product will be built, commissioned, operated, maintained, decommissioned and disposed of. (Fiona Begg, personal communication)

Begg includes the PETE analysis at any stage from concept development through to design definition.

7.3.3 Misconception analysis

In research seeking to characterise the misconceptions that designers and operators have about complex engineered systems that could be implicated in accidents, Busby (2003) identified about 30 types of misconceptions held by designers and about 20 types of misconceptions held by operators. Table 2 provides some examples.

Table 2: Examples of designer and operator misconceptions (Busby, 2003)

Designer misconceptions		Operator misconceptions
Wrong beliefs	Missing beliefs	
Adaptive behaviour The belief that operators will update their knowledge when they use new equipment – whereas they sometimes rely on knowledge acquired when using old equipment *Guaranteed operating procedures* The belief that operating procedures can avoid a harm that is inherent in the design – whereas procedures may be too general and are often violated *Sustained attention* The belief that operators will sustain high attention levels – whereas attention is	*Confounded goal* Not anticipating how the design could stop an operator meeting a reasonable goal and resorting to a hazardous behaviour *Unintended use* Not anticipating that the design appears to be capable of being used in unintended ways *Wrong-sense interpretation* Not anticipating that the design gives a display which can be interpreted in a wrong sense	Alarms which contradict other indicators can be ignored When equipment stops you carrying out your task it's faulty The past is a good guide to the future Everyday intuition is a good guide to hazards All you need to know is contained in procedures Work or attention can be offloaded onto safety systems

Busby (2003) recommended that the potential for such misconceptions be considered by both designers and operators as part of the hazard analysis process in developing and evaluating a design. A tool developed to assist designers and operators perform this analysis received a mixed response in a provisional evaluation; while use of the tool proved time-consuming and users made many suggestions for improvement, it was found to be useful in identifying misconceptions with potential for increasing risk (Busby, 2003).

7.3.4 Work system analysis (e.g. FRAM)

Section 5 introduced the importance of understanding work as a complex sociotechnical system and how the difference between work-as-imagined and work-as-done should inform

the design. In relatively less complex designs, PETE analysis or CWA may be sufficient to gain such an understanding. For more complex environments where human, technological and organisational functions form part of the system and the designs, a functional model of the system can facilitate understanding between multiple stakeholders. The Functional Resonance Analysis Method (FRAM) may be used to model the functioning of a system. In a FRAM analysis, work activities are analysed in order to produce a model or representation of how work is done (Hollnagel, 2018. This model can be used for a range of purposes to improve system resilience, including checking for unintended consequences, identifying bottlenecks or effects of variability, testing the feasibility of proposed solutions and identifying the most effective solution(s). For information on the use of FRAM, see Hollnagel (2018).

7.4 Technical design

While the human-centred approach requires engagement with multiple stakeholders who may interact with the designed product, the design professionals (e.g. engineers, ergonomist/human factors professionals and OHS professionals) must ensure that technical requirements address current and future use. OHS professionals have a role in ensuring that:

- Technical requirements are considered as part of a desk-top review at the concept development stage
- Initial drawings and specifications for the design are assessed to ensure that the technical requirements are considered and integrated at the design definition stage of the project in consultation with the user representatives.

Some key technical requirements are discussed below.

Compliance with legislation and standards

Legislation applying to design may go beyond OHS legislation (section 4) to include a range of technical, environmental and other legislation. Legislation relevant to both the build and final designed product may vary across Australian states and internationally. In some cases, the legislation may not align with internal company design criteria or standards. Compliance criteria for design (and procurement) should be established, taking account of legislation across countries of operation, national and international standards and internal company standards.

Constructability

The life-cycle approach to design requires that OHS is considered at all stages of the design, including construction or manufacture of the designed product (see SWA, 2018). Thus, from the concept phase, through feasibility to design definition, the design must address how the product will be built, skills required, issues that might be encountered and

potential work methods (or work arounds) that might be employed during construction, and associated hazards and risks.

Maintainability and operability

As noted previously, design for users must address use in the broadest sense, including maintenance and cleaning. Two important aspects of usability are manual and materials handling, and access for manual operation by operators and for maintenance. Maintenance may be onsite or may require isolation, removal and re-installation for offsite maintenance. Other aspects of access and operability important in design considerations include access to emergency stops.

Human-machine interface

While there is a push to reduce the interface of humans with equipment (e.g. driverless cars), design must consider the human-machine interface. Traditionally, design of this interface has been based on important ergonomic principles such as readability of dials and gauges, alarm systems, grip and strength requirements, posture and manual handling, and alarm and response systems. Awareness of designer and operator misconceptions (section 7.3.3) and an understanding of the variability of human behaviour (section 5) are also important considerations. Design of the human-machine interface presents an opportunity to explore productivity gains in parallel with risk reduction (see, for example, EASHW, 2009).

Operational interface

Design should include consideration of how the designed product will interface with existing equipment, other planned equipment and changes to process.

Organisational interface

The design needs to consider how the organisation impacts the way work is actually done, including the influence of the local work group, the department and the wider corporate culture as well as any external influences such as the nature of the industry, regulations and economic considerations.

Risk controls commensurate with potential consequences

Hazard and risk analysis processes (section 7.5) should identify any circumstances where users of the designed product, or others, are exposed to a critical/fatality risk at any stage of the design life cycle. Where such risks occur, the design should incorporate critical controls, which not only require engineering and other controls to eliminate or reduce the risk to as low as reasonably practicable, but also include assurance systems to establish that controls are in place and working. Design reviews for critical risk identification and control are ideally completed early in the process when the cost of change is minimal. For guidance on developing and implementing critical controls, see ICMM (2015a,b).

Competency requirements

Identification of competencies required by constructors, operators/maintainers is an integral part of the design process.

Design assurance

Checking of design specifications such as strength, load capacity or operating parameters may be required for some designs. Quality control to ensure that the design is constructed as per the specification is part of the design process.

7.5 Hazard and risk analysis

Human-centred safe design differs from traditional technical design in its approach to systematic risk assessment. Lingard et al. (2014) warn that applying a linear risk assessment process (and subsequent control actions) to design (which is flexible, dynamic and iterative) assumes that all hazards are clearly identifiable at the time of the initial risk assessment. If a hazard is not identified at that time it is excluded from subsequent analysis. Thus, in line with the iterative nature of the design process, hazard identification and risk assessment should also be dynamic and revisited as the design develops. The consultation and engagement strategies described in Appendix 1 will assist in identifying hazards and risks, but are not a substitute for formal risk assessment.

Hazard and risk analysis should include, as appropriate, safety risk assessment, ergonomic risk assessment and health risk assessment.

7.5.1 Safety risk assessment[7]

The nature of the safety risk assessment will depend on the complexity of the design and the nature of human interaction with the design, its function and operation. Risk assessments for more complex designs with high risk may include techniques such as hazard and operability studies, failure mode and effects analysis, industry-specific tools such as CHAIR and work systems analysis. Whatever safety risk assessment methodology is used, the focus will be on identifying energies, particularly sources of stored energy that may not be immediately obvious,[8] and the interactions between multiple stakeholders and the technology employed.

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[7] See *OHS BoK* 12.3 Managing Process Safety for a discussion on complex safety risk assessment processes.

[8] See *OHS BoK* 15 Hazard as a Concept for a discussion on an energy-based hazard classification.

Hazard and Operability (HAZOP) studies are often used in the early-design phase of complex process designs to identify potential design shortcomings, and in the detailed engineering phase to assess the completed design for issues that may have been missed in previous reviews.[9] HAZOP studies have been successfully modified and applied to processes that are significantly mechanical in nature.

Failure Mode and Effects Analysis (FMEA) is a technique used to systematically identify and assess vulnerabilities in a system through the proactive identification of ways in which a system could fail (failure modes) and the potential outcomes of those failures (effects). The methodology has evolved from a purely engineering focus (looking at technical component failures) to encompass examination of system and process vulnerabilities that might arise due to human error.[10]

CHAIR (Construction Hazard Assessment Implication Review), a tool used in the construction industry, provides a discussion framework stimulated by guidewords "to review the conceptual design and identify the significant construction, maintenance, repair and demolition safety risks associated with a project" (WorkCover NSW, 2001, p. 10). Two sets of guidewords – *generic* and *overview* – are used to trigger thinking about hazards. Generic guidewords used for each design element are size, position/location, movement/direction, energy, egress/access, heights/depths, maintenance/repair, poor ergonomics, load/force and timing; and overview guidewords used for the whole design concept are environmental conditions, toxicity, environmental impact, inspection/testing, documentation, quality control, external safety interfaces, commission/start-up/shut down, safety equipment, natural hazards, demolition, construction equipment fire/explosion, utilities and services, and maintenance. The user systematically works through the guidewords one by one (not unlike a HAZOP study) (WorkCover NSW, 2001).

Safety in Design Ergonomics (SiDE) tool[11] is a task-oriented risk assessment process that focuses on human interaction with equipment. While it was developed to ensure the safety of operators and maintainers in the mining industry (to examine site-specific issues for new equipment, inform investigation of equipment-related incidents, and address residual risks during equipment operation and modification), SiDE has application across other highly technical operations to identify and assess risk associated with the human-technical interface, especially where equipment may be procured internationally.

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[9] See *OHS BoK* 12.3 Managing Process Safety for further discussion on HAZOP.

[10] See *OHS BoK 34.2* An Introduction to User-Centred Safe Design.

[11] See *OHS BoK 34.2* An Introduction to User-Centred Safe Design.

7.5.2 Ergonomic risk assessment

Ergonomics and human factors take a systems approach to risk assessment in design. Considering user feedback and the human impact of the proposed design, the ergonomist and human factors specialists will consider all aspects of the design, including physical, physiological, psychological and social characteristics.

Ergonomic risk assessments may include:

- Physical risk assessments such as:
  - OWAS (Ovako Working Posture Analysing System) – evaluates postural load during work
  - RULA (Rapid Upper Limb Assessment) – postural targeting method for estimating the risks of work-related upper limb disorders
  - Revised NIOSH Lifting Equation – assesses risk associated with lifting or lowering
  - 3D Static Strength Prediction Program (3D SSP) – software that predicts static strength requirements for tasks such as lifts, presses, pushes and pulls.

  For more information, see Neumann (2006).

- Psychosocial and work organisation assessments such as:
  - Work Organisation Assessment Questionnaire (WOAQ) – assesses work organisation in a manufacturing setting
  - Copenhagen Psychosocial Questionnaire (COPSOQ) – provides a standardised and validated approach to assessing a variety of psychosocial factors
  - Karasek Job Content Questionnaire – assesses psychological demands, decision latitude, social support, physical demands and job security.

  For more information, see Shea and De Cieri (2011).

Depending on the nature of the design, both qualitative and quantitative evaluation measures may be relevant.

7.5.3 Health risk assessment

Health risk assessment is “The process of estimating the potential impact of a chemical, biological, physical or social agent on a specified human population system under a specific set of conditions and for a certain timeframe” (Spickett, Brown, Matisons & Katscherian, 2006, p. 4). A health risk assessment for a designed product will consider the outcomes of the safety risk assessment and the ergonomic assessment, and will also consider any associated chemical, biological, social psychological health impacts. Four important factors in health assessments related to these hazards are: dose-response relationship, exposure assessments, vulnerabilities of the exposed groups, and working relationships between the

users of the design (Spickett et al., 2006). Where a health risk assessment is required, the generalist OHS professional should advocate for the involvement of an occupational hygienist and/or occupational and environmental physician, and if a design may have psychosocial impacts then the input of an organisational psychologist may be appropriate.[12] (For guidelines on environmental health risk assessments, see enHealth, 2012.)

7.6 Design decision making

Effective, efficient and safe design requires an informed, systematic decision-making process. Models for structured decision making with phased project approval have been developed for large complex projects. Such models of pre-approval activity – referred to as pre-feasibility study (PFS), early project planning (EPP) or front-end loading (FEL) – emphasise the importance of key decisions made early in the project for effective delivery within budget and time frames. For more information, see for example Shlopak, Emblemsvåg and Oterhals, 2014.

While the main purpose of pre-approval activity is to make sure the final product has a high probability of meeting investment hurdles set by the business, it can be adapted to also ensure that OHS and usability requirements are addressed. Irrespective of whether the design project is a small one controlled by one or two people or a more complex project involving a multidisciplinary team, such structured processes should inform the design.

Most projects that follow a PFS/EPP/FEL process break the pre-approval work into manageable sequential phases with each phase having greater detail and accuracy. As each phase concludes, its output is assessed to determine whether the development will progress to subsequent stages. This assessment and approval is known as a Decision Gate. Only the minimal work needed to achieve the specified Decision Gate criteria is performed in any given phase. Objectives and activities associated with decision making in each design stage are outlined in Table 3.

[12] See *OHS BoK* 34.4 Design of Work (in planning at time of writing of this chapter).

Table 3: Objectives and activities for systematic decision making in the three traditional design stages

	Concept development	Feasibility assessment[13]	Design definition
Objective	To determine the basic economic viability of the product/design	To evaluate the feasibility of the design and whether it will achieve the intended objectives	To establish the detailed criteria for final approval and execution of the design
Activities	• Identify where/when the designed product will be used (e.g. environment, context, specific site) • Assess impact of the intended product on the work, the people and the business • Select the appropriate technology (if any) to be incorporated into the design • Estimate cost of design, construction, implementation, operation throughout life cycle (+/- 50%) • Benchmark the intended product against designs for similar purpose • Assess life cycle and sustainability of the designed product • Conduct a high-level hazard identification and risk assessment for the designed product throughout its life cycle	• Conduct an analysis of the system(s) (e.g. PETE analysis) where the design will operate throughout its life cycle • Conduct a detailed risk assessment on the designed product for each stage of the life cycle • Prepare design specification • Develop a milestone schedule for the design and implementation • Refine cost estimates (+/- 25%) • Check any permit or regulatory requirements	• Define the purpose and scope of the design • Prepare detailed specifications, drawings, etc., for construction/manufacture • Document assessment of the impact of the design on the work, the people and the business • Review and refine risk assessments on the designed product for each stage of the life cycle • Develop specifications for any procurement, especially where there is a long lead time • Develop detailed implementation plan and schedule, including commissioning and start up • Refine cost estimate (+/- 10-15%) • Lodge submissions for any permits or regulatory approvals

While decision making associated with small design projects will be much simpler, the process should still be disciplined and systematic. Such a process could be based on answering questions such as those listed in Table 4.

[13] Many pre-project planning models split feasibility into two or more sub-stages, including pre-feasibility. The pre-feasibility stage offers more opportunity for influence as the latter phases of the feasibility stage tend to focus on economic feasibility.

Table 4: Modified systematic design decision making for small projects

Design stage	Questions to address
Concept development	What does the design need to do? Who will use the design? Where will the design be used? How will it be used (throughout the life cycle)?
Feasibility assessment	What hazards and risks are associated with the construction, use (and other stages of the life) of the design? How will the design impact the nature of the work, the people and the business? Are any modifications required to the workplace or to the work? Are there any regulations, permits or standards associated with the design? What will the design cost throughout its life cycle?
Design definition	What are the specifications for the design? What is the implementation plan, including any training or modifications to workplace, equipment or procedures?

In section 1.1, design was defined as a "staged, iterative process." The iterative nature of design is largely associated with the concept development and early feasibility stages as once the design has been defined and specifications determined, there is often little scope for change. Consequently, it is important to consider health and safety implications early in the design process.

7.7 'Design' in the procurement process

Although legislation places certain obligations on importers and suppliers of plant and equipment (section 4), it is not sufficient to rely on these to ensure the safe design of purchased plant and equipment. Depending on the complexity and risk associated with the purchased plant and equipment, the procurement process should follow a similar analysis process to that outlined in section 7.6. Table 5 maps a procurement question-based decision-making process to the three design stages.

Table 5: Systematic decision making for procurement processes mapped to the three design stages

Design stage	Procurement phase	Questions to address
Concept development	Describe context and use	What does the product need to do? Who will use the product? Where will it be used? How will it be used (throughout the life cycle)?
Feasibility assessment	Identified need to purchase	What hazards and risks are associated with the assembly, use, maintenance, storage, decommissioning, dismantling or disposal of the product? How will the product impact the nature of the work, the people and the business? Are any modifications required to the workplace or the work? Are there any regulations, permits or standards associated with the product? What will the product cost throughout its life cycle? Are there any residual risks associated with use of the product? How can these risks be further reduced? Is the residual risk acceptable?
Design definition	Development of purchase specification and approved supplier	What are the specifications for purchase? What is the implementation plan, including any training or modifications to workplace, equipment or procedures?

8 The role of the professionals

Preceding sections have highlighted the need for a collaborative approach to safe design of plant and equipment and the environment in which they are used. Collaborative team members may include engineers and ergonomists as well as generalist OHS professionals, who are the workplace advocates for safe design. In some cases, specialist advice may be sought from professionals in other disciplines such as occupational hygiene.

8.1 Engineers

"Historically, mainstream engineering was divided into the four broad disciplines of chemical, civil, electrical and mechanical engineering, with several branches within each discipline covering an enormous range of fields" (Engineers Australia, n.d.). Other disciplines of engineering have emerged or are developing that are technology or industry based (e.g. marine, mining, agricultural, mechatronics, biomedical) or discipline based (e.g. materials, software, risk). Australia's principal engineering association, Engineers Australia, recognises

three occupational categories based on educational qualifications: Professional Engineer, Engineering Technologist and Engineering Associate. The design role for each engineering category is likely to include the following:

> *Professional Engineer* – may lead the design team, setting the design criteria or standard; depending on the prevailing legislation, the Professional Engineer may also need to be registered in the relevant field of practice[14]
>
> *Engineering Technologist* – may lead the manufacturing or construction team, participating in the detailed design process to comply with the design standard; may make minor changes to an existing design within set parameters
>
> *Engineering Associate* – prepares designs based on the design decisions made by others utilising codes and standards as appropriate. (Engineers Australia, 2019)

8.2 Ergonomists

Ergonomists are technical and process experts who apply an evidence base to optimise human wellbeing and systems performance to address the physical, cognitive and psychosocial requirements of the design. They take a systems approach to assess the design, applying knowledge from discipline areas such as anthropometry and biomechanics, usability assessments using simulations and prototyping, and qualitative and quantitative assessments of the workplace in consultation with users and management stakeholders. Ergonomists take a collaborative approach to design, working with a range of stakeholders including engineers, architects, designers, users and managers at both the conceptual and design definition stages.

In Australia, a Certified Professional Ergonomist (CPE) is recognised as a qualified and competent ergonomist who has applied for and been accepted by a certification board supported by the Human Factors and Ergonomics Society of Australia (HFESA). Such certification requires completing an education program that addresses ergonomic competencies and a minimum period of practice in human factors and ergonomics (HFESA, 2019). Non-CPE ergonomists may have a general understanding of ergonomics, but either have not sought certification or not fulfilled the requirements.

8.3 Occupational hygienists and occupational physicians

Occupational hygienists can make an important contribution to health risk assessments (section 7.5.3), in understanding the nature and action of physical hazards and their health implications, in assessing exposure and in designing to eliminate or minimise such hazards. As occupational physicians take a holistic approach to health within a workplace and

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[14] In Queensland, the *Professional Engineers Act 2002* provides for Registered Engineers.

environmental context, they may also play an important role in identifying and addressing health impacts of designed products.

8.4 OHS professionals

While not a design expert, the generalist OHS professional can have a significant influence on safe design. With a multidisciplinary background, the OHS professional has a range of skills that enable a holistic view of the design process, and can advocate for an inclusive approach to design while ‘challenging’ the thinking around the design in the manner of the ‘black hat’ in Edward de Bono’s ‘six thinking hats’ model:

> The Black Hat’ is judgment – the devil’s advocate or why something may not work. Spot the difficulties and dangers; where things might go wrong. Probably the most powerful and useful of the Hats but a problem if overused. (The de Bono Group, n.d.)

Key to this role is knowing the right questions to ask. Appendix 1 provides a question-based tool developed by the expert panel to guide the OHS professional in taking such a questioning role.

The role of the OHS professional will depend on the complexity of the project, the technical requirements of the design and the availability of specialist expertise. In supporting a team approach to design, the role will include:

- Raising issues early in the design cycle
- Ensuring a life-cycle approach so that all users are considered
- Supporting, and in some cases facilitating, communication and consultation between users and those involved in design, ensuring that the users have appropriate information to enable a shared understanding of the design and its impact on their work
- Contributing to a structured, systematic analysis of the design context and potential use of the designed product by asking probing questions
- Ensuring that the analysis of the design context is based on work-as-done rather than work-as-imagined
- Contributing to the evaluation of the interaction between the designed product and the physical and social environment in relation to technology, the workplace and the organisation of work, and how that might impact users and the product in both the present and the future
- Ensuring risk assessments encompass all stages of the design process
- Advocating for, and facilitating where required, the engagement of ergonomists, engineers and other design specialists as appropriate
- Supporting the documentation of due diligence in design and procurement.

The focus of the OHS professional is not only on the physical design of a product, but also on best fit with the work environment, the culture of the organisation and the work group, the systems of work, and the needs and capabilities of workers and others who may interact with the designed product.

The OHS professional's role may prove challenging when financial and economic pressures are brought to the design process to 'trim' so-called non-essential aspects of the design. In such cases, the OHS professional should have access to information and data to justify the inclusion of safety and health aspects of the design. A safe design process will usually produce a better designed product that will pay for itself through efficiency gains, usability and in safety and health outcomes. The challenge is for the generalist OHS professional to demonstrate these benefits.

9 The importance of safe design in practice

The concepts of safe design can be applied to any design project, from the smallest tool to complex plant, and to the physical work environment. The case studies below highlight the importance of safe design.

Work analysis as part of design

Beveridge manufacture and logistics

Cartons of drinks are high-volume consumer items with supply impacted by seasonal weather conditions. This includes soft drinks, alcohol and other high-volume items such as bottled water and milk. Engineering studies to reduce the costs of transportation and improve product delivery quality and presentation to the customer identified the movement of cartons in the truck during transportation and whilst being moved by forklift as an area for improvement. Environmental and waste-handling reduction programs through the supply chain identified that wrapping these pallets of cartons with multiple layers of plastic added to the product costs and increased environmental impacts.

An engineering design change introduced a glue product between the layers of cartons to hold them more securely on the pallet for transportation, and enable elimination or reduction in the amount of plastic wrap for the pallets.

In the warehouse, the cartons are picked for the stores. When the order pickers select from the glued cartons they need to twist or flip the carton to break the spots of glue with the carton below. If they don't do this they are potentially lifting two cartons, resulting in an increased risk of manual-handling injuries.

The marketing department may change the packaging of the drinks depending on promotional needs. Changing the cardboard material and the finish to the carton can change the adhesive capacity of the glue, which can increase or reduce the force to separate the cartons.

It was noted that the work is often done by labour hire contractors, who may not be aware of which products are glued until they are 'picking' that product as part of the order.

In introducing the glued product, no consideration was given to safety or health impacts, including the manual-handling impact of the packaging and the chemical impact of the glue on the packers.

David Caple (personal communication, November, 2108)

Error tolerant design that fails safe

Dropped Mancage

The mancage attached to a 50 tonne crane free fell about 10 metres until the crane driver applied the winch brake to arrest the fall. Two employees were in the mancage at the time and suffered significant injuries. They had been attaching hand railing to the top of a silo and were in the process of being lowered to the ground. The crane driver had previously applied the slew brake via a lever to prevent the crane from slewing due to the windy conditions. In the process of lowering the mancage, the crane driver went to release the slew brake via a lever on his right-hand side. In front of the slew brake lever there are two levers controlling the crane free-fall mode, one for the main hook and one for the auxiliary hook. Both the free-fall levers have a manually applied latch to prevent accidental movement of the levers. [As required by the work procedure,] the crane driver was watching the mancage and rigger while reaching for the slew brake lever. Instead of grabbing the slew brake lever he reached forward approximately 150mm and operated the free fall control lever. The manual latch was not in place and the lever was moved, allowing the auxiliary hook and mancage to free fall.

The driver realised almost instantly that the mancage was free falling and activated the footbrake, which arrested the mancage after falling about 10 metres. When the mancage stopped, one employee sustained severe facial lacerations and the other sustained leg injuries.

Direct and indirect causes of the accident

- The crane driver had set the manual latch for the free-fall control lever in the incorrect position.
- The free-fall latch was not fail-safe, it required vigilance from the operator to ensure that the latch was in the correct position.
- The free-fall latch did not have any alarm or require another function to be carried out by the operator to disengage the latch and operate the free-fall lever… (Power, 2017)

This is an example of ensuring the appropriate equipment for the task. Cranes are not generally designed for lifting humans safely; lift hoists have additional fail-safe design features inherent in the design standards.

Human-machine interface

BP Texas City Refinery Explosion

On March 23, 2005, the restarting of a hydrocarbon isomerisation unit resulted in a series of explosions. Fifteen people were killed and a further 180 were injured. The Chemical Safety Board (CSB) found that the computerised control board display contributed to the overfilling of the raffinate tower.

The CSB report (2007) described two critical flaws in the design of the display:

- The flow into the unit was displayed on a different screen to the flow out of the unit.
- No material balance calculation was present to highlight the imbalance between the two flow readings.

The CSB found that the location of the two feeds on two different screens diminished the visibility and importance of monitoring liquid in and out, and did not alert the operator to the imbalance between the two flow readings. (NOPSEMA, 2015, p. 7)

An automatic high-level cut-off was not incorporated to give fail-safe operation.

Systems approach to designing for a changing population

Medical retrieval and treatment of bariatric patients

New challenges in treatment and care of patients have emerged with the increasing number of people who are heavier with a larger body mass. Known as bariatric patients, their representation in hospital and patient care has continued to grow over the past 20 years. The bariatric patient is complex and presents a new range of design criteria needing to be accommodated at all stages of the healthcare process, including retrieval and transport to hospital and care within the hospital environment.

Conventional ambulances, stretchers, wheelchairs and other patient handling equipment are not designed to accommodate the larger and heavier person. They either don't have the structural capacity for heavier 'loads' or the patient simply can't fit within these devices. The early transportation of bariatric patients to hospital was ad hoc, with adapted vehicles, equipment and methods. For example, a small truck and ramp would be used to drag a patient on a large mattress into the vehicle. This relied on many people assisting, and the patient and paramedics would be unrestrained while travelling to the hospital. These methods didn't provide the same level of care, safety and patient dignity as that afforded 'conventional' patients because appropriate equipment to move and transport them did not exist.

Whole-of-system approaches were undertaken by ambulance services and equipment manufacturers to develop new designs for ambulances and bariatric patient-specific handling and transportation equipment to accommodate this emerging patient group. Body size and shape data to inform and guide these new designs was (and remains) very limited.

These new designs had to provide safer methods of getting the patient from their accommodation to the ambulance. The resultant equipment included inflatable, air pressure devices to move the patient vertically and horizontally, larger and more structurally capable wheelchairs, stretchers and patient-sliding devices. Powered devices were developed to raise and lower the patient on a stretcher to load them into the ambulance to replace the hazardous manual exertion of very high forces by paramedics. The size and shape of new stretchers needed to accommodate the large body mass and soft tissue of the bariatric patient to contain them within fixed spatial parameters within an ambulance. Stretcher design features also had to accommodate the medical requirements of these patients, who need to lie in a semi-upright posture to maintain their breathing capability. Special methods for restraint of the bariatric patient within the ambulance were developed to protect the patient and maintain the regulatory requirements for all items and persons to be restrained within the moving ambulance. The accommodation of paramedics within ambulances was configured to maintain the general automotive safety requirements of facing forward or rearward and being restrained during movement of the vehicle, as well as the accommodation of additional treatment personnel who may b

The second wave of design consideration has addressed the accommodation and handling of patients within the hospital environment. This has led to the development of specialist wards where beds are wider with a higher load capacity, wider doorways and patient rooms designed to enable the

beds and patients to be moved within the facility. Overhead tracking and hoist systems have been developed to mechanically raise and lower the patient and move them horizontally between their bed and other devices such as a wheelchair, toilet or shower. All these devices require structural integrity to protect the patient and those providing care and treatment.

Access to the larger bariatric patient is more awkward for those providing care simply because of the greater body size of this patient group. This has required new design criteria to enable good patient access for care givers so they can maintain high-quality care while limiting risk of injury during these activities. This element of design around this patient cohort remains a challenge and presents as the next wave of design improvement within this system.

The complexity of bariatric retrieval, treatment and accommodation has required engineering and human factors specialists to work together to develop new designs that enable the delivery of equivalent levels of care and safety for patients and those treating them across the entire system of care.

Chris Fitzgerald (personal communication, November 2018)

Maintainability: Hazard identification at design phase

Crush injury during planned maintenance

In August 2013, an electrician at a surface mine site was conducting planned maintenance work which involved "lubricating an electric motor on a tripper conveyor drive unit. The tripper was set in automatic mode, moving back and forth over surge bins. A ladder was fitted to the tripper unit and traversed over the electrical termination box creating a crush point. The electrician's head was caught between the ladder and the electrical cable termination box [resulting in a] fatal crush injury to the head." (DMIRS, 2018)

The investigation findings included that the engineering design of the tripper unit created a crush hazard. Hazard identification at design phase and guarding and remote greasing points would prevent hazards with moving machine components. (DMIRS, 2018)

Design integrity and impact of modifications

Leach tank failure

A leach tank at a mine failed catastrophically, releasing "a slurry of ground ore, water and acid within the processing area…" (ERA, 2014). While the leachate was contained within the processing area, there was potential to impact an environmentally sensitive national park.

The sequence of events leading to the tank failure was identified as:

- Modification of the tank to add a higher-powered agitator
- The modification contributed to partial failure of a baffle (which influences the movement of material to ensure effective mixing)
- Through wear and tear, the partially failed baffle damaged the rubber lining of the tank
- The damage in the rubber lining allowed the acidic slurry to come in contact with the tank's

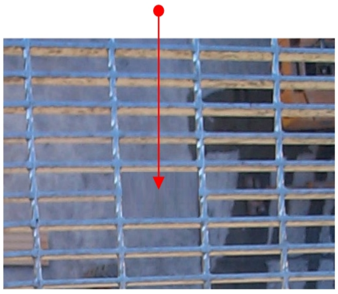
"Inspections identified the occurrence of metal fatigue in the baffle supports [and so the company] decided to redesign and replace the baffle supports in all of the leach tanks before they [were] returned to service." (ERA, 2014). The design decision to use a rubber tank lining in such an acidic environment was also revised

Design assurance

Flooring grid mesh not to specification presenting gravitation hazard

An iron ore screening plant was in the final stage of construction. Grid mesh walkways, kick plates and hand rails had been installed over several levels and the installation had been inspected and signed off as satisfactory for operations.

Missing Grid Mesh Bar – 100 mm by 60 mm opening



The grid mesh was purchased and imported from an overseas manufacturer. The design specified grid mesh flooring with an opening of 100 mm by 30 mm as it allowed any iron ore spillage in the form of small particles to pass or be washed through, but prevented larger rocks from falling to levels be

It was mandatory for tradespeople such as fitters and boilermakers to place their smaller tools and equipment on a mat or in a container on the mesh flooring to prevent them falling through the open mesh or to physically retain their smaller tools using a tool lanyard attached to the employee. On the day of the incident, a large crow bar around 1.5 m in length with a width of 40 mm was being used. This size was sufficient to prevent it penetrating the 30mm opening in the grid mesh. The crow bar was inadvertently dropped by the employee onto the grid mesh.

Unfortunately, the grid mesh was defective; it was missing an intermediate cross bar and presented an opening of around 60 mm which allowed the crow bar to fall several levels. No one was injured.

A detailed examination of grid mesh across the project found several instances of defective 'out of specification' grid mesh panels.

Contributing factors were identified as:

- Inadequate quality control at the manufacturer's overseas premises
- Inadequate inspection of the grid mesh by the construction contractor at the point of receival and unpacking
- Inadequate inspection of the installed grid mesh by the construction contractor and client representative.

Craig Power, iSol8 (personal communication, 2018).

10 Implications for OHS practice

Irrespective of the size or complexity of a design (or procurement) process, generalist OHS professionals should be able to advocate for and advise on application of the principles of safe design. These principles are:

1. Hazards should be eliminated or risk minimised by applying the hierarchy of control early in the design process.
2. Design should be recognised as an iterative process with systematic risk management (identify, assess and control) applied throughout.
3. Safe design should address the full life cycle of the design.
4. Design is a collaborative process involving multidisciplinary input, including input from those who will use the designed product.
5. Design should address the needs of users, with users defined in the broadest sense.
6. Design should be human-centred, taking account of human variability and variability in use of the design.
7. Design should be tolerant of variations in use.
8. Information and communication need to be managed throughout the design process to support safe design.

OHS professionals may meet a number of challenges in advocating for safe design.

- Design is often seen as an engineering function with the OHS professional not involved in the process or only brought in at the implementation phase.
- Design projects are often budget-driven, with a fixed allocation for design analysis and risk assessment. Such constraints may make it difficult to treat risk assessment as an iterative process mirroring the iterative stages in the early design process. Budget allocation may also set restrictions on timeframes and the range of people consulted and involved in risk assessments.

OHS professionals need to be able to demonstrate their value in the design process. Relevant technical knowledge is a basic requirement.[15] Knowledge of the particular industry and its work, and familiarity with the 'language' of the industry and the organisation, will enable OHS professionals to ask appropriate questions to stimulate critical analysis of safety and health impacts, as well as usability, as part of the design process. They do not need to know the answers to the questions. (See Appendix 1 for a guide to questions to be asked.)

OHS professionals need to stimulate such critical analysis without being seen as 'project stoppers.' They need communication skills to sell the message that putting time into getting

[15] See *OHS BoK* 12.3 Managing Process Safety for an introduction to engineering drawings.

good design is good for business, and they need awareness of what different disciplines can bring to the design process and where they best fit. This requires information such as examples of where designs have failed, and learnings from reviews of previous design and procurement activities, and an ability to push discussion to include 'future gazing' with examples of good design. An understanding of justification of cost-benefit analysis can assist OHS professionals in advocating for safe design, which is more than legislative compliance.

As with all hazard management and risk control, controls at the top of the hierarchy should be prioritised. OHS professionals have a role in ensuring that less reliable controls such as procedures and personal protective equipment are not used to counteract poor design.[16]

The OHS professional is an advocate for safe design and should look for opportunities to get involved early in the design process and to make safe design a priority.

11 Summary

While difficult to quantify, evidence suggests that the design of tools, plant and workplaces is a significant contributing factor to workplace fatality, injury and ill health. Addressing health and safety early in the design process is effective in reducing incidences of injury and ill health, and also from a financial perspective.

Safe design – recognised as a strategic action area in the *Australian Work Health and Safety Strategy 2012-22* (SWA, 2012) – has become a key component in OHS risk control. However, approaches to safe design can be limited by viewing design as a linear process whereas in practice it is complex and iterative, and must take account of the life cycle of the designed product, including its concept development, design, manufacture, procurement, supply/install, commissioning, operation and maintenance, decommissioning, dismantling and disposal. This complexity impacts:

- Identification of users
- Analysis of the way in which the product will be used
- Analysis of the environment in which the product will be used
- Assessment of the risk created by use of the product to 'users' and others
- The controls that may be implemented.

[16] Refer to *OHS BoK* 13 Rules, Procedures and Documentation for a discussion on issues around use of procedures as controls.

As an advocate for, and facilitator of, safe design, the OHS professional must understand this complexity and ensure that the principles of safe design are applied to all design projects.

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Appendix 1: OHS in the design process – A tool for OHS professionals

These questions and responses were generated through workshop discussion by the panel of expert advisors. Questions and matters for consideration have been enhanced through reference to Read (2015) and Plattner (2017).

Questions the OHS professional might ask or consider?	Follow-up questions, matters for consideration
1 Design team	
Who should be on the design team?	Have we got the skills required? (Technical skills as well as attributes such as collaborative skills, creative and integrative thinking, being open to and valuing range of input.) What discipline, knowledge and attributes are required for the core of the team and what other advice might be required? Are end users, stakeholders and subject matter experts represented? Is a design 'champion' required?
Who should facilitate the design team?	Should have appropriate skills to: • Focus on process rather than content • Encourage and support collaboration and engagement • Keep process on track.
2 Design process	
Have the design governance processes been clarified?	Approval (What is required for signoff? Who signs off? Do they have the required knowledge?) What processes will be applied to manage changes to the design? What communication and consultation processes will be in place? Are all stakeholders included in the communication and consultation processes?
Does the design process allow for user consultation, including modelling, prototyping and testing?	What attributes of the user group need to be considered to ensure the consultation is effective? What modelling processes best suit the design and the user group?
3 Concept development	
3.1 Context	
Why is this project being undertaken?	Is it in response to OHS concerns, an incident, risk assessment, customer response, economic, routine renewal …?
What is the purpose of the design?	What is the designed product required to do? Are there any performance criteria for the designed product?

Questions the OHS professional might ask or consider?	Follow-up questions, matters for consideration
What is the scope of the design process?	How much will be specified in the design? What might be left to commissioning/implementation? What are the OHS implications of leaving some decisions to later stages in the design process?
What is the intended life for the design output?	What might the life depend on? How long could the design be in use? What factors might limit/extend its life?
Are there any strategic factors that should be considered in the design?	How does the design fit with the strategic direction of the organisation? How might the workplace, technology, workforce change over time? How might the use of the design change over time?
Are there any financial limitations, parameters set for the project?	While financial factors should not override safety, the OHS professional should be aware of any stated financial parameters.
Are there other organisational constraints that may impact the design or implementation of the design?	Constraints may relate to industrial relations, HR, company values, moral or cultural constraints, deadlines or schedules, etc.
Are there any assumptions underpinning the process?	Assumptions may be stated or unstated. What unstated assumptions may exist that need to be clarified?
3.2 Users and others	
Who will interact with the output of the design over its life cycle? (construction/manufacture, install, commissioning, operating, cleaning, maintaining, decommissioning, dismantling, disposal)	What are the abilities of the user groups? Will they require new knowledge and skills? What are the physical characteristics of the user groups? (see anthropometry) How will the design consider current and future variation in these groups?
What are the access, maintainability and usability requirements?	Where will the design be located? What is the surrounding environment – physical obstacles, lighting, exposure to weather? Can operators access the area and the required controls? Will maintenance be conducted in situ or is there a policy of rotable change out? How are maintainable items removed, what is the sequence of removal, are risks associated with the removal process (taking grid mesh out, removing handrails or lifting over work areas)? Have tooling lay-down areas, mobile equipment access and frequency of access been considered?
In addition to the users, who are the other stakeholders in the design?	Technical advisors? Production manager? Finance? Marketing? Workers who are not direct users? Customers? Suppliers? Community?

Questions the OHS professional might ask or consider?	Follow-up questions, matters for consideration
3.3 Research	
What information is available internally and externally on functionality, OHS and environmental impacts?	Sources of information may include regulators, legal case history, hazard alerts, industry bodies, specialist advisors, and informal and formal networks.
What legislation or standards may impact the design?	WHS legislation? Other technical or industrial legislation? AS/NZS and ISO standards? Industry standards?
What hazards are associated with the design? How might these hazards impact health and safety of the users and others who interact with the design?	Have the hazard identification and risk assessments considered all stages of the life cycle of the designed product? Have the hazard identification and risk assessments considered users in the broadest sense? Have the hazard identification and risk assessments been reviewed with any changes to the design?
What ergonomic or engineering principles or technical specifications may impact the design?	Is there a need to consult with an ergonomist or engineer? What sort of specialist engineering, ergonomic or other skills/knowledge are required?
What are the likely environmental impacts from the manufacture/construction, commissioning, operating, cleaning, maintaining, decommissioning, dismantling or disposal?	Is environmental, occupational hygiene or occupational health expertise required?
3.4 Analysis	
In what physical, psychosocial and organisational environment will the design be used?	Is organisational psychology expertise required?
What are the 'system' components within which the design will be developed and implemented?	System components may include organisational priorities, management and supervisory structures, HR and industrial relations environment, dependence on and integration with other work processes and work practices.
How will the design be used?	PETE (people, equipment, tasks and environment) analysis for each user at each stage: **P**EOPLE likely to use and/or be in the area (workers, operators, maintenance, cleaners, contractors) **E**QUIPMENT that will be used in association with the design **T**ASKS that will be undertaken using the design or in the area of the design

Questions the OHS professional might ask or consider?	Follow-up questions, matters for consideration
	ENVIRONMENT in which the design will be used, including environmental stressors such as heat/cold, weather, chemicals, 'wear and tear.'
3.4.1 Design for construction and manufacture	
How will the design be manufactured/constructed?	e.g. off site, on ground / above ground? Who will undertake the manufacture/construction? In-house/contractor? Skills required? Supervision?
What are the decisions required as part of the manufacture/ construction?	What will be the critical control points in the construction?
What hazards might be encountered during construction/manufacture?	How will these hazards be addressed? Are Safe Work Method Statements (SWMS) required?
How might the organisation of the work impact the construction and safety aspects?	What overlaps might occur in scheduling trades? What might be the impact if there are delays in some stages of the construction?
How adaptable is the construction methodology to address unforeseen developments?	How might delays, cost-overruns, supply delays or other contingencies impact the integrity of the design? Will current SWMS require revision? Will additional skills be required?
What might be the impact of modification in design?	Who might be affected by the modifications? Consider those constructing or manufacturing the designed product, those who commission operation of the product, those who maintain or clean the product, operational users, those who may decommission or dispose of the product as well as functions such as procurement and training. In what ways might these groups be impacted?
3.4.2 Design for supply/install	
What criteria will be specified for procurement of designed item or parts?	Are there relevant standards that should be considered? Have the criteria been tested? What flexibility will be allowed in meeting the criteria? Is there any additional risk?
3.4.3 Design for commissioning	
Are processes in place to verify that the product is built as designed?	What arrangements will be required for inspection and testing against the design?

Questions the OHS professional might ask or consider?	Follow-up questions, matters for consideration
How will the installation/ commissioning be staged?	PETE review for each stage of installation? (walk the lines or step through the process) What risk assessments are required for each scenario/stage of commissioning? What procedures might need to be developed?
What testing might be required at each stage?	
What simulations/scenarios might be tested?	
What could go wrong?	What could go wrong during commissioning? If something does go wrong, how will a quick shut down work? What precautions should be taken during testing to minimise risk associated with any failures during testing?
3.4.4 Design for use	
PETE review	P – skilled operators E – reliability, running time, operating envelopes T – parameters for use (when properly used), potential for variations in use, other purposing, instructions, procedures E – suitability for/of the environment intended for use.
Is it fit for purpose?	Have appropriate risk assessments been conducted taking account of the complexity of the design, the hazards and level of risk? Does it meet operational requirements, including allowing for variability in inputs as well as use? Does it meet performance requirements?
What record keeping is required?	Procedures, operational hours or conditions?
What are the energy demands of the design?	Are there modifications that could conserve energy?
What sustainability issues might be associated with the design?	Supply of raw materials?
3.4.5 Design for maintenance	
What will be the maintenance requirements?	Is maintenance required, how often, by whom? Will maintenance be undertaken in a workshop or on site? What access will be required for maintenance? What requirements might there be to replace parts? Is there a policy of rotable changeover of parts?
Is isolation required for maintenance?	What energies will be present and require isolation? Can the energies be reliably isolated and/or discharged? What isolation procedures will be applied? Physical lock out / procedural tag out? Reliability?

Questions the OHS professional might ask or consider?	Follow-up questions, matters for consideration
PETE review	P – skills required for maintenance E – access equipment required T – frequency of maintenance, predictability of maintenance (programmed/breakdown) E – accessibility
What record keeping will be required as part of maintenance?	Inspections? Checks? Service?
3.4.6 Design for de-commissioning/disposal	
PETE review	P – skills required for decommissioning E – special equipment required for decommissioning T – how will parts be broken down? what raw materials might have accumulated? E – how/where will parts be disposed of?.
4 Design approval	
4.1 Design evaluation	
Has the design considered the full life cycle of the designed product?	Life cycle includes construction/manufacture, supply/install, commissioning, use, maintenance, decommissioning, disposal.
Will the design work? What OHS issues might be associated with the design? (Design testing)	User group meeting(s) to review schematic design with a focus on health and safety. Focus and questions will depend on the nature and purpose of design and user group.
	Are mock-ups, models or prototypes required to fully analyse functionality and potential OHS issues?
What OHS issues associated with the design should have been identified through the design testing?	Check back with hazard identifications, risk assessments and other internal and external information.
What design modifications are required to address OHS issues?	While the OHS professional may make recommendations, it is not the role of the OHS professional to define the required design changes. There may be a number of ways to address the identified issue(s). These design modifications should be similarly subjected to design testing to ensure the identified issues have been addressed without introducing new hazards/issues.
Has design testing identified the need for processes to support implementation of the design?	Implementation support processes may include modification to the workplace, training, development of work procedures, and supervision. Is a communication strategy required?

Questions the OHS professional might ask or consider?	Follow-up questions, matters for consideration
4.2 Design brief	
Have the design changes identified through design testing been included in the design?	What evidence is required to demonstrate inclusion to an appropriate standard? Is further consultation or testing required on the design modifications?
Does the design brief clearly state design specifications and design description to ensure it is constructed as intended?	Design brief may include diagrams, photos, computer-generated models and screen shots of interfaces.
Have support processes required for implementation of design been documented and provision made?	Appropriately skilled personnel? Time for orientation and training? Maintenance resources and scheduling?
Does the design and associated documentation clearly address identified OHS issues?	Would a safety-case approach be helpful/appropriate?
Have the short-term OHS issues related to the construction and installation and any impact on others been identified and addressed in related documentation?	
Are any contractor requirements clearly defined?	Are OHS requirements addressed in the contractor documentation? Are OHS criteria a basis for contractor selection? Have the required skills been considered in contractor selection?
Have any procurement specifications been clearly defined?	
Have stakeholders had opportunity to review and provide input to final design?	
Is OHS sign-off part of the approval process?	Who, and what level of authority, is appropriate for sign-off?
5 Verification	
Has the design as implemented met the	Evaluation should address both short-term implementation as well as longer-term monitoring. May require accessing a range of views.

Questions the OHS professional might ask or consider?	Follow-up questions, matters for consideration
specifications in the project brief?	
Have any unforeseen issues arisen relating to safety, health, usability or engineering integrity of the design?	Is it safe to use in its current form? How is it planned to address these issues? Is re-design required?
6 Reflection	
What lessons have been learned through the design process?	What might be done better next time?

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