Prevention and Intervention

Core Body of Knowledge for the Generalist OHS Professional

Safety Institute of Australia Ltd

Australian OHS Education Accreditation Board

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 in Australia* provides a context by describing the role and professional environment.

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Prevention and Intervention

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Abstract

Hazard and risk control to prevent work-related fatality, injury, disease and ill health is the core objective of the OHS professional. While there is a legislative requirement to control risks in the workplace, the approach should go beyond mere compliance. Control of hazards and risk is not necessarily an easy or straightforward task. While the methods of controlling individual hazards such as chemicals and noise are well understood, there are many workplace injuries and disorders that have multiple causes, and there are different approaches to control. This chapter addresses key principles of control including requisite variety, hierarchies of control, time-sequence approaches, barriers and defences, the precautionary principle and the sociotechnical systems approach. A brief discussion of specific control strategies is followed by consideration of the implications for OHS practice. The chapter emphasises the role of the OHS professional as an organisational change agent, rather than just a risk-management technician.

Keywords

control, barriers, defences, hierarchy of control, safe design, systems

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1 Introduction

The role of the generalist OHS professional is to "provide enterprises with advice on the organisational arrangements that will lead to the systemic and systematic management of OHS to prevent work-related fatality, injury, disease and ill-health (FIDI)."[1] This advice includes recommending appropriate and effective prevention and intervention strategies to manage hazards and risks. Developing effective control strategies requires an understanding of the causation of fatality, injury, disease and ill health,[2] and of the role of the organisational environment;[3] this understanding is informed by knowledge of the biology[4] and psychology of workers as individuals[5] and in groups.[6]

Control of hazards is a complex topic and there are many views. It is not the intention of this chapter, nor would it be possible, to exhaustively cover all relevant models and approaches to control. Rather, this chapter builds on the knowledge of causation outlined in the OHS Body of Knowledge *Models of Causation: Safety* and *Models of Causation: Health Determinants* to review some key principles such as:

- the hierarchy of control
- the time sequence for employing various control strategies
- barriers and defences
- the precautionary principle
- an introduction of a sociotechnical systems approach.

The chapter concludes with an examination of the implications for OHS practice. The principles of control addressed in this chapter are extended to the mitigation phase in the OHS Body of Knowledge Mitigation – *Emergency Preparedness* and *Mitigation – Health Impacts*. Referring to the bow-tie representation of risk (see Figure 3), this chapter deals with the prevention side (left side of the bow-tie), whereas the chapters on mitigation deal with the right side of the bow-tie.

1.1 Definitions

The terms 'hazard management/control' and 'risk management/control' are often used interchangeably; this gives the false impression that 'hazard' and 'risk' are synonymous. There are various definitions of 'hazard' in both community and OHS contexts; however, the fundamental test of whether something is a hazard is whether its elimination would

[1] *OHS BoK* Introduction.
[2] See *OHS BoK* Models of Causation: Safety and *OHS BoK* Models of Causation: Health Determinants.
[3] See *OHS BoK* The Organisation, *OHS BoK* Organisational Culture and *OHS BoK* Systems.
[4] See *OHS BoK* The Human: As a Biological System.
[5] See *OHS BoK* The Human: Basic Psychological Principles.
[6] See *OHS BoK* The Human: Basic Principles of Social Interaction.

result in the elimination of risk.[7] 'Risk,' a more complex concept, is often perceived as a product of likelihood and consequence of specific outcomes; also, it may be considered as a description of the effect of uncertainty on objectives with there being a plethora of factors impacting on the uncertainty and the potential outcomes. The descriptive view of risk recognises that the purpose of OHS risk management is not to reduce loss at all costs, but to achieve objectives as effectively as reasonably practicable with the 'control' phase usually referred to as 'risk treatment.'[8]

Management of specific hazards to prevent work-related fatality, injury, disease and ill-health is addressed in the hazard-specific chapters of the OHS Body of Knowledge. As it is not possible to eliminate all hazards, there will always be residual risk, which must be managed. This chapter's use of the term 'control' refers to controlling the complexity of risk sources and interactions that is necessary for management of residual risk as opposed to treatment of specific risks.

2 Historical context

The study of causation and control of work-related disease and ill-health has a long history with written references dating to ancient Rome.[9] The first book on the control of industrial hazards was Georgius Agricola's 1556 *De Re Metallica* (*On the Nature of Metals*), which discussed the need for ventilation machines in mines to replenish the air and prevent suffocation. Published in 1700, Bernardino Ramazzini's *De Morbis Artificum Diatriba* (*Diseases of Workers*) – the first major medical text that linked conditions of work with diseases – stressed the importance of personal cleanliness and protective clothing (see Hunter, 1957). Since then, control of occupational disease and ill-health has been dominated by a medical model that focuses on treatment of individuals after their expression of symptoms of ill health.[10] In the late 20th century, this individual medical approach was complemented by a systems and organisational approach to occupational health (and safety) that seeks to reduce risk and hence reduce adverse outcomes.[11] In more recent times, the trend is towards a positive occupational health and safety experience with the concept of good work, good jobs and supportive organisations. (See Kendall et al., 2015)

In contrast to occupational health, accident research and our understanding of causation of traumatic workplace injury began relatively recently. The 1931 publication of Herbert Heinrich's *Industrial Accident Prevention: A Scientific Approach* was the first major work

[7] See *OHS BoK* Hazard as a Concept.
[8] See *OHS BoK* Risk.
[9] See, for example, *OHS BoK* Physical Hazards: Thermal Environment and *OHS BoK* Noise and Vibration.
[10] See *OHS BoK* The Generalist OHS Professional in Australia (Appendix) .
[11] See *OHS BoK* Systems and *OHS BoK* The Organisation. For a discussion of models of causation related to health, see *OHS BoK* Models of Causation: Health Determinants.

focussed on understanding accident causation. Based on analysis of some 75,000 accident reports, Heinrich concluded that the majority of accidents were due to unsafe acts, which in turn were the result of faulty attitudes of careless or reckless individuals. This led to the concept of the 'unsafe worker,' which resulted in control measures focusing on the behaviour of the individual worker (Heinrich, 1931).

However, blaming the worker (generally the victim within the incident) has been decried by a range of OHS professionals, regulators and unions because it does nothing to reduce the inherent risks within the workplace. While "blaming individuals is emotionally more satisfying than targeting institutions…continued adherence to this approach is likely to thwart the development of safer [organisations]" (Reason, 2000, p. 768). The idea that it makes more sense to analyse the incident process, and control relevant steps in that process, led to a switch in emphasis from 'safe person' to 'safe place' (see, for example, Gallagher, 2001).

An example of this 'safe person' versus 'safe place' argument, and its potential to harbour complexity, is provided by the relative efficacy of airbags and seatbelts in protecting people in car crashes in the US (Baker & Haddon, 1974; Culvenor, 1996). In a crash, the airbag, which is always present in the car, inflates automatically. Conversely, the seatbelt only works if the occupant has buckled up. In the 1970s, attempts to increase voluntary use of seatbelts in the US were generally unsuccessful (Baker & Haddon, 1974). The 'safe place' seemed to trump the 'safe person' argument. However, the situation is not that simple. As observed by Hollnagel (2008, pp. 221–222), "perfect prevention is impossible [because] there is always something that can go wrong." As a result of the force involved in deploying the US-type airbags, "169 child deaths have been attributed to injuries from an airbag since 1992" in the US (Lennon, Siskind & Haworth, 2008). Conversely:

> …there have been no reports of a child injured or killed by a passenger airbag in Australia [where airbags]…are designed as supplementary restraint systems, intended to operate in conjunction with restrained passengers. As such they fire at lower speeds and later delays than the more aggressive 'first generation' style of bag fitted to US vehicles prior to 1998…which makes them less likely to cause injury (Lennon, Siskind & Haworth, 2008).

The approach works because seat belt usage in Australia is high among drivers (>97%) and children (>90%) (Lennon, Siskind & Haworth, 2008). These usage rates were achieved by behavioural-based programs (advertising, education) backed by strong police enforcement. The lesson is that a combination of 'safe place' and 'safe person' provides a better outcome than either 'safe place' or 'safe person' alone.

Contemporary theory and research suggest that the failures that lead to incidents can be attributed to a combination of factors such as human error[12], inadequate design, poor

[12] Accidents generally arise from an active failure which is usually the result of human error. As Reason (2000) noted, the important issue is not focussing on the error itself, but on what were the systems, organisation and / or environmental factors that led to the error. Fixing those latent conditions will eliminate a series of potential future human errors.

maintenance, degradation of working practices, inadequate training, poor supervision and excessive working hours, which in turn are influenced by organisational and management culture (see, for example, Trbojevic, 2008). Factors that may impact on causation of work-related ill-health include the physical and psychosocial work environments, personal vulnerabilities, and many occupational diseases and disorders.[13] Work is continuing to address issues of complexity within organisations and how this changes the need for additional models to understand how accidents could occur and be prevented in complex processes.

3 Understanding the principles of control

It may seem obvious that if a risk is identified, it should be eliminated. However, a risk-free environment is neither possible nor desirable. The law does not require a risk-free work environment where "accidents never happen," but instead requires employers "to take such steps as are practicable to provide and maintain a safe working environment" (Harper in *Holmes v R. E. Spence & Co Pty Ltd* as cited by Malcolm, 1999, p. 6)[14].

When faced with risk, options range from doing nothing (i.e. accepting the risk) to eliminating the risk. Between these extremes are risk-reduction options aimed at decreasing the probability or likelihood that the hazard becomes uncontrolled, and /or mitigating the effects of the consequences of the risk. The OHS professional needs to understand this variability and be able to develop the most appropriate options in any set of circumstances. This section discusses some of the major principles underpinning the control of risk.

3.1 The problem of requisite variety

This discussion on controls starts in an area that may be largely unknown to the OHS profession, the problem of requisite variety. The law of requisite variety was developed by Ashby (1956, p.207) and can be stated as "only variety can destroy variety."[15] Hollnagel (2011) states this law as:

$$\text{Minimum (Variety}_{\text{Outcome}}) = \text{Variety}_{\text{System}} - \text{Variety}_{\text{Regulator}}$$

This means that to achieve stability of a system, the variety of the regulator (or the controls in the system) must be the same in number as the variety (the different states possible) in the system. Risks in organisations can be understood to arise from the interaction of people, equipment and systems, and can be dealt with only by using a sufficient variety of control actions to cover all of the possible ways that the system can go wrong (Nævestad, 2008). Reason, Parker and Lawton (1998) in discussing rules within organisations, note

[13] See *OHS BoK* Models of Causation: Health Determinants

[14] See also *OHS BoK* Principles of OHS Law for a discussion on 'reasonably practicable'.

[15] See *OHS BoK* Systems.

that “in virtually all productive activities carried out in potentially hazardous circumstances, the variety of possible unsafe behaviours is very much greater than that of the required productive behaviours” (p.297). In tightly coupled, complex processes, the variety that exists in the system to be managed exceeds the variety (i.e. capabilities) of the people who need to control it (Weick, 1987).

In the above equation, we can reduce the variety of the outcome by either decreasing the variety of the system, or increasing the variety of the regulator, or a combination of both. The most common (but not necessarily the best) way is to increase the variety of the regulator, generally by increasing the number of rules. Reason, Parker and Lawton (1998) argue that although theoretically feasibly, it is generally not possible to develop rules to cover all possible permutations and situations in a production process. Generally the variety of rules developed to govern safe behaviour will always be less than the variety of unsafe situations. Attempts to increase the number of rules in this way generally result in situations where rules may contradict each other or where workers are forced to violate rules to achieve production goals (Reason, 1997). Multiple and sometimes contradictory rules have been implicated in the Glenbrook, Waterfall and Longford disasters (Hopkins, 2005).

The other way to balance the equation is to reduce the variety in the system. This can be done by reducing the complexity of the system. In his studies of high reliability systems, Karl Weick identifies a key way of reducing system complexity as being to create locally responsive systems that are easier to comprehend and easier to keep track of (Weick, 1989). A way of doing this is increasing delegation of control to the smallest viable system in the organisation, rather than trying to control from the centre through rule-making. One way of achieving this is to prefer (as appropriate) rules requiring goals to be achieved, as distinct from rules defining concrete actions or required states of the system (See for example Hale and Swusts, 1998). The former gives the local unit the capacity to adapt the goal-based rule to local circumstances, while still achieving the organisational goals, whereas the latter is prescriptive, and does not take into account local issues that may hinder application of the rules.

Another technique to balance the above equation, also arising from high reliability studies and not generally thought of as a control measure, is to increase collective diversity in decision-making (Weick, 1987). This ensures effective consultation with all relevant stakeholders when making decisions about risk controls. Weick (1987) notes that a team of divergent individuals has more requisite variety than a team of homogeneous individuals. It should be noted that such effective consultation is not what is commonly seen as the legislated duty of quarterly meetings of the OHS committee. It is about continuous conversations and sharing observations and knowledge between different interacting groups – management, operations, OHS, shop floor, etc., such that the collective diversity increases requisite variety which in turn improves reliability (Weick, 1987). Such

continuous conversations and trust are at the heart of new approaches such as high reliability and resilience engineering and represent a paradigm shift in thinking on accident causation (See for example, Woods, Dekker, Cook, Johannesen and Sarter, 2010).

3.2 Hierarchies of control

The concept of a hierarchy of control strategies underpins OHS legislation and most workplace control actions. Originally developed for occupational hygiene applications,[16] the hierarchy of control establishes the priority order in which hazard and risk controls should be considered. When applied in the broader OHS context, the hierarchy of control is a problem-solving tool to promote creative thinking when developing options for risk control rather than a fixed set of rules. Figure 1 is one representation of a hierarchy of control that highlights the relative protection and reliability of controls. American variations of the hierarchy of control insert ‘warnings’ (covering alarms, gas detection, signs, etc) after engineering controls.[17]

In interactively complex technologies, individual element failures may interact in ways that are impossible to see, anticipate or comprehend.[18] If a hazard is controlled by an engineering device, for example, there is still potential for failure of the device, its misuse, lack of understanding of its operation, lack of maintenance and so on. Even in a ‘simple’ situation, a large variety of factors may need to be controlled. Typically this would involve developing procedures for the control action, training workers and supervisors in the use of these procedures, applying supervision to ensure compliance with procedures, applying maintenance schedules to mechanical devices, and routinely reviewing or auditing the overall situation to ensure that the control actions achieve their intended effect over time. Clearly this is more complex than is indicated by ‘apply engineering control’ and is an example of appropriate requisite variety required to control the system.

The hierarchy of control should be used to identify the most effective control, which is generally in the elimination, substitution or engineering varieties. However, this should not be considered the only control, as clearly other lower order controls such as procedures, training and supervision are required, and indeed prescribed by legislation.[19]

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[16] The concept was developed in 1950’s by the US National Safety Council. Early versions did not include “elimination”. Olishifski (1976, p.439), as did other writers of the time, identified the hierarchy as: substitution, alteration of the workplace, isolation or enclosure, wet methods to reduce dust exposure, local exhaust, general ventilation, personal protective devices, good housekeeping, medical controls, and training.

[17] See sec 5.1.1 ANSI/AIHA Z10-2005 American National Standard for Occupational Health and Safety Systems where the hierarchy is given as: elimination, substitution, engineering controls, warnings, administrative controls, and PPE.

[18] See *OHS BoK* Global Concept: Safety and *OHS BoK* Global Concept: Health.

[19] See for example, 21(2)(e) of the *Occupational Health & Safety Act,* 2004 (Vic).

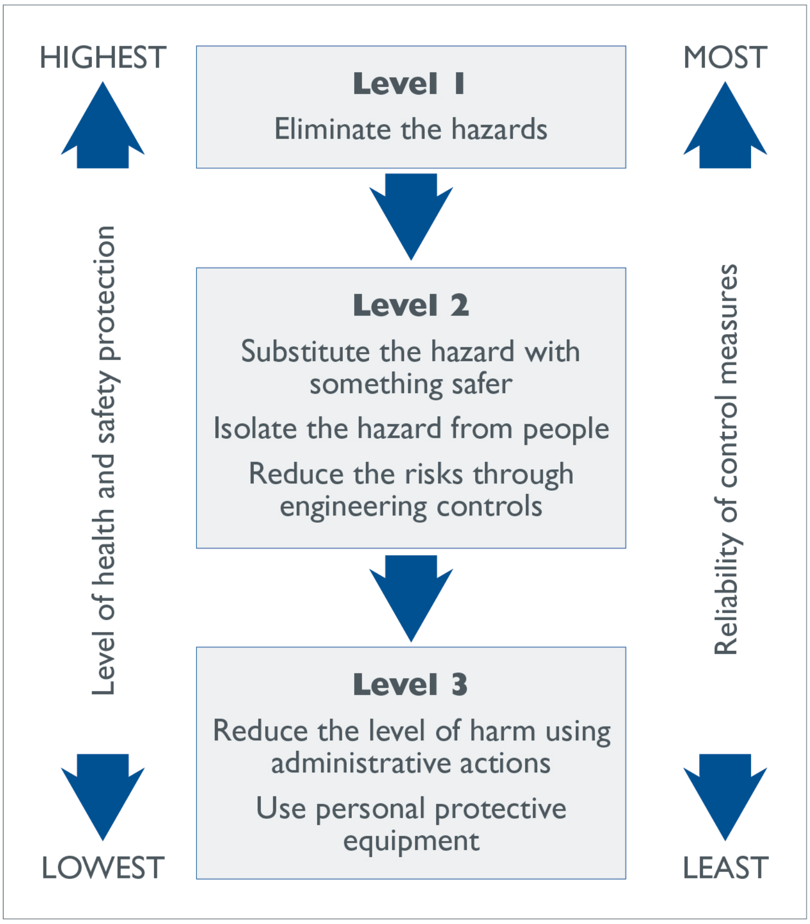

Figure 1: Hierarchy of control (SWA, 2011a, p. 13)

Training and supervision are explicit administrative control measures that are critical and necessary barriers and apply in conjunction with all other forms of control. When regulators prosecute organisations for breaches of safety legislation, they almost always prosecute for absent or inappropriate training and/or supervision of workers. Creighton and Rozen (2007) found that almost all prosecutions under the *Occupational Health and Safety Act 1985* (Vic) were for employer breaches of s 21(1) the general duty of care, s 21(2)(a) safe plant and/or safe systems of work, and s 21(2)(e) provision of information, instruction, training or supervision. This has not changed in more recent times.

While the requirement for training and supervision applies across a range of hazards and risks, other administrative controls such as safe-work procedures and risk assessments apply to specific hazards.

The traditional hierarchy of control (e.g. Figure 1) works reasonably well for separate physical risks such as plant or hazardous chemicals; however, it is not suited to all risks, particularly psychosocial risks (Maxwell, 2004). In addition, the hierarchy has been abused by oversimplification. In any situation where a control is imposed, particularly where

elimination or substitution is involved, the potential for unintended consequences must be considered. For example, Hollnagel (2008) noted that elimination of human involvement as a result of automation may change the basis for risk assessment in a fundamental way, and it is not appropriate to claim that such 'elimination' reduces risk unless the short-term and long-term consequences are fully taken into account. Indeed, automation introduces a different range of risks that were not considered in the original risk assessment and therefore necessitates a new risk assessment.

3.3 Time sequence

Models of causation (and consequently the theory underpinning development of control strategies) may be considered in three categories: simple sequential linear models, complex linear models, and complex non-linear models.[20] While different models suit different circumstances and levels of complexity, most models feature a 'time-sequence' factor, which provides a framework for development of control strategies that goes some way to addressing the over-simplification of many hierarchies of control.

In developing controls it is useful to envisage a time sequence that commences before the incident and extends beyond it to include damage or injury outcomes. This allows controls to be considered in a variety of prevention and mitigation modes. It is also necessary when addressing accident investigation to ensure a clear understanding of what happened and when. Viner's (2015) generalised time-sequence accident model includes:

- A *pre-conditions* time zone, during which conditions supporting possible event mechanisms develop
- An *occurrence* time zone that includes the initiation of the event mechanism and the specific outcome
- A *consequence* time zone, during which damage commences, is detected and proceeds to completion, followed by recovery or stabilisation.

Also taking a time-sequence approach, Sklet (2006) related generic safety functions to accident phases in a process model in which the pre-event phase is referred to as the 'normal condition' (Figure 2).

> The generic safety functions *prevent*, *control*, and *mitigate* are related to the transitions between the different phases in [this process] model. To prevent means to prevent transition from normal condition to a state of lack of control. To control means to prevent transition from lack of control to loss of control, while to mitigate means to prevent the targets starting to absorb energy. (Sklet, 2006, p. 498)

[20] See *OHS BoK* Models of Causation: Safety

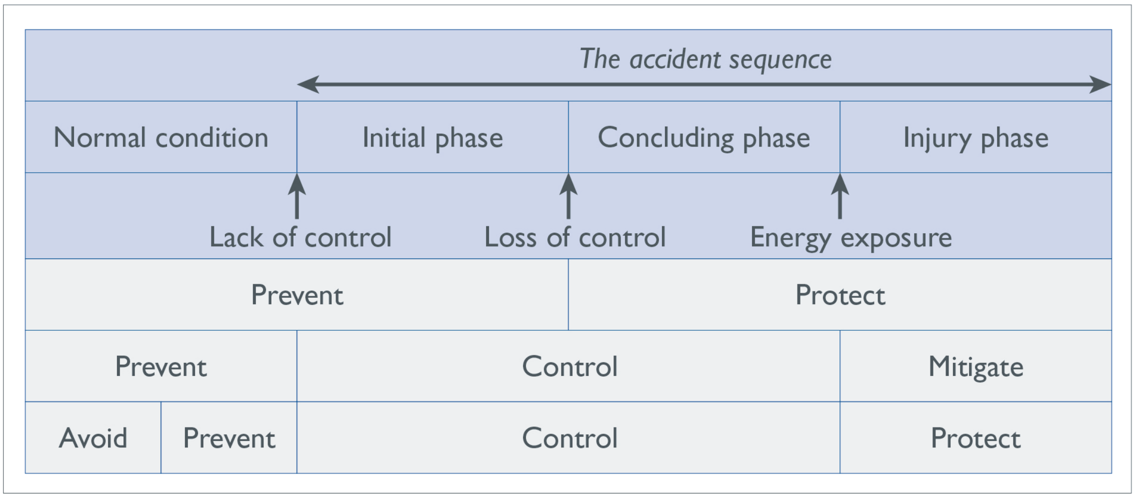

Figure 2: Generic safety functions on a time sequence (Sklet, 2006, p. 498)

Haddon (1970) developed ten strategies that follow a time sequence to control energy flows. Strategies 1–8 are pre-event and 9–10 are post-event, although there is capacity for overlap:

1. Prevent the build-up of relevant energy inventory in the first instance (e.g. after the introduction of Dangerous Goods legislation in the 1980s, many organisations eliminated fuel bowsers in their vehicle depots to eliminate risk and legal compliance issues).
2. Reduce the energy inventory (e.g. reduce flammable liquids onsite to a minimum).
3. Prevent the release of energy from the inventory (e.g. barriers around open excavations).
4. Modify the rate of release or distribution of energy from the source (e.g. use of mufflers).
5. Separate in time or space the energy from the susceptible structure (e.g. put power lines out of reach).
6. Separate by use of material barriers (e.g. electrical and thermal insulation).
7. Modify the contact surface, subsurface or basic structure (e.g. eliminate sharp surfaces that could result in cuts).
8. Reduce losses in people and property by strengthening structures that might be damaged (e.g. use of building codes in earthquake-prone regions).
9. Limit loss by rapidly detecting and mitigating damage, or countering the spread (e.g. fire detectors and sprinklers).
10. Stabilisation of the damage and system recovery, covering all recovery aspects from first aid and medical interventions, rebuilding after a fire, and repairing damaged plant or vehicles.

A time-sequence approach to occupational disease and ill-health control strategies may be considered in similar pre-conditions, occurrence and consequence phases. For example:

- Control in the pre-conditions phase:
  - Control of specific hazards, such as chemical or biological hazards that cause specific diseases or initiate responses such as asthma
  - System-wide occupational health management strategies integrated into the OHS management system
  - Health promotion activities focusing on individual vulnerabilities and causal factors
- Control in the occurrence phase:
  - Adaptive response by a competent operator as a process variable starts to move outside of safe parameters.
  - Active management of the individual by medical and other health professionals once a medical condition presents (e.g. management of a lead worker)
  - System-wide occupational health interventions
- Control in the consequence phase:
  - Support for injured workers and others who may be affected
  - 'Return to work' strategies.

This time sequence can be visualised by a 'bow tie' diagram, which can be used to identify all the ways that an incident may occur, the barriers or other controls are in place, and the mitigation strategies to reduce the consequences of the event if the controls fail. The incident is called the top or critical event[21] with the hazards and prevention requirements on the left of the critical event, and the mitigating strategies and consequences on the right, as shown in Figure 3. Mitigation strategies may include: actions for system recovery; emergency management; medical treatment; and rehabilitation and return to work.

[21] A separate 'Bow-tie' is required for each top event.

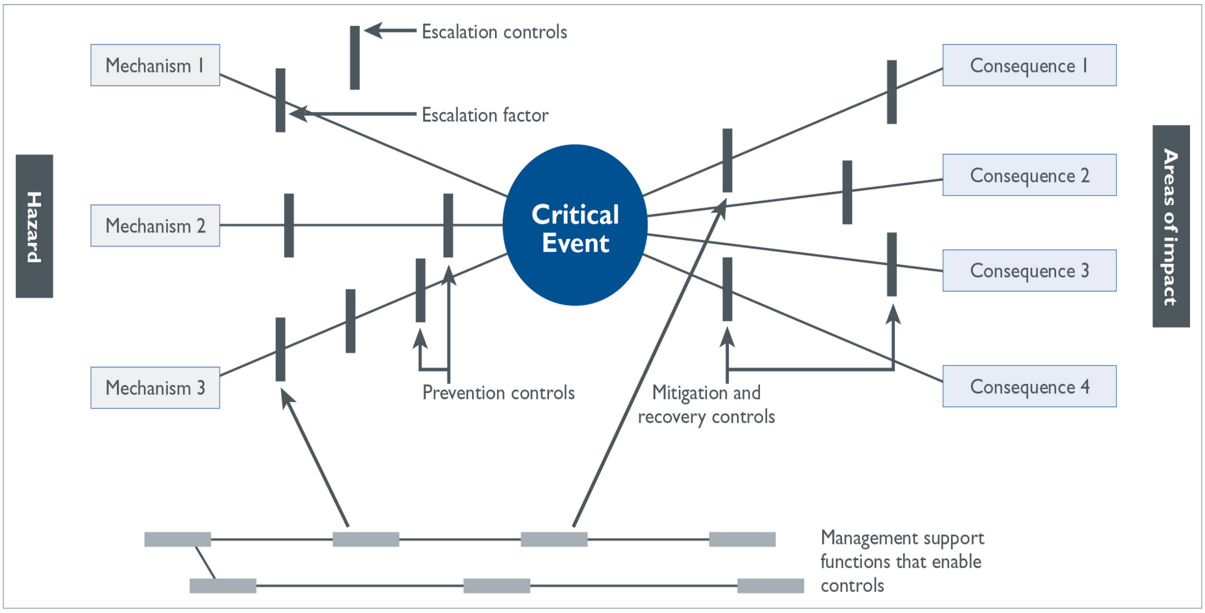

Figure 3: Bow tie model of risk (modified from Hudson & Guchelaar, 2003)

3.4 Barriers and defences

Models of causation that consider barriers and defences build on the concept of requisite variety. Identification of defences and barriers, and how these may break down or be defeated, is important in understanding causation. Knowledge of the role of barriers and their development is equally important in the development of control strategies.

Haddon (1970) introduced the notion of safety barriers, with specific reference to physical constraints. More recently, it has been suggested that safety barriers are not limited to the physical. As described by Trbojevic (2008, p. 4), a barrier is a design feature, which "may be physical or non-physical or a combination, and the intent is to prevent, control, mitigate or protect from accidents or undesired events." In explaining his 'Swiss cheese model of system accidents', Reason (2000, p. 769) referred to barriers, or defensive layers, within technology systems in the following manner:

> …some are engineered (alarms, physical barriers, automatic shutdowns, etc.), some rely on people (surgeons, anaesthetists, pilots, control room operators, etc.), and yet others depend on procedures and administrative controls…In an ideal world each defensive layer would be intact. In reality, however, they are more like slices of Swiss cheese, having many holes – though…these holes are continually opening, shutting and shifting their location. The presence of holes in any one "slice" does not normally cause a bad outcome. Usually, this can happen only when the holes in many layers momentarily line up to permit a trajectory of accident opportunity – bringing hazards into damaging contact with victims.

Hollnagel (2008) provided examples of social barriers, organisational barriers, hardware barriers, cultural barriers, behavioural barriers and human barriers. Based on the work of

Hollnagel (2008) and Sklet (2006), Trbojevic (2008) proposed a barrier classification scheme (Figure 4).

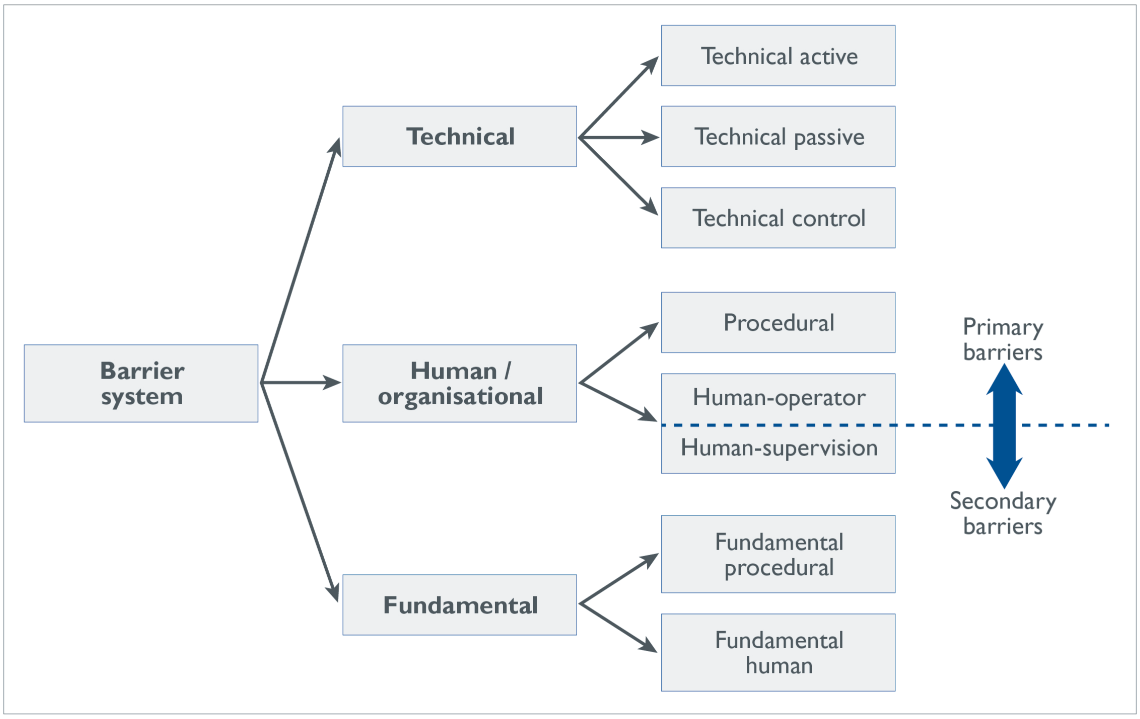

Figure 4: Barrier classification scheme (modified from Trbojevic, 2008, p. 18)

Trbojevic (2008) classified technical, human/organisational and fundamental barriers according to their effectiveness in controlling risk:

1. *Technical barriers* (high effectiveness) – can prevent risk escalation, attenuate the risk, mitigate its consequence or reduce its likelihood. Subcategories:
    a) *Technical active barriers,* which perform on demand (e.g. a fire sprinkler system)
    b) *Technical passive barriers*, which perform all the time (e.g. a fire wall)
    c) *Technical control barriers*, which activate other prevention or mitigation system (e.g. a gas or fire detection system).
2. *Human/organisational barriers* (medium effectiveness) – contribute to the control of the process or activity, and reduce the likelihood of initiating events by reinforcing barriers or preventing their decay. Subcategories:
    a) *Organisational (procedural) barriers*, which include procedural controls, permit-to-work systems, job safety analyses, inspection and monitoring, and controlling instrumentation
    b) *Human (operator) barriers*, which include the competence of the operator within their job

c) *Human (supervision) barriers*, which include the supervision of the activity by management.

3. *Fundamental barriers* (low effectiveness) – barriers separated in time from threat initiation and risk realisation. Fundamental barriers contribute to system safety by checking for system weaknesses and any underlying or latent failures (see, for example, Reason, 1997). Subcategories:
   a) *Fundamental procedural barriers*, which include design reviews, procedural reviews, operational reviews, system audits, etc.; examples of such applications are the Tripod Beta[22] analysis (see Reason, 1997), which determines 'general failure types' within the operation that are most likely to contribute to unsafe acts, and the Incident Cause Analysis Method (ICAM) investigation process (Gibb, Reason, De Landre & Placanica, 2004)
   b) *Fundamental human barrier* covering the good health / wellness of the workforce (Trbojevic, 2008).

Trbojevic's primary barriers (Figure 3), which function "to eliminate, prevent, reduce, mitigate or control threat transmission and [risk] escalation," are fortified by the secondary barriers, which "prevent barrier decay, erosion or failure," as well as underlying or latent failure/decay, thereby improving reliability and energising the sociotechnical system (Trbojevic, 2008, p. 19). Barrier theory provides a richer and more comprehensive model than energy-control models or hierarchies of control.

The relevance of the concept of barrier decay for OHS professionals is highlighted by the potential for organisations to 'drift into failure'; "Workplace accidents rarely happen out of the blue. Generally, there is an incubation period, a time during which practices and assumptions about risk change slowly and gradually."(Dekker, 2012.) All systems degrade unless specific resources are committed to halt or reverse the decay; machines wear out, shortcuts are taken with procedures, workers leave the organisation and reasons for doing things in a particular way are forgotten. This has been emphasised in Turner's disaster incubation theory, which postulates that as time passes, organisations start ignoring and misconstruing danger signals, and those with good safety records become complacent (Turner & Pidgeon, 1997, in Shrivastava et al, 2009). Thus controlling barrier decay should be a key component of the OHS management system.

[22] Tripod Beta is a proprietary product (see www.advisafe.com/tripod) that reviews work processes for latent failures (general failure types), prior to any accident occurring in an attempt to reduce the probability of such an accident. It is based on Reason's model and is the only such comprehensive tool to the author's knowledge. It is used in the petrochemical industry. De Landre et al., (2006) suggest that ICAM (Incident Cause Analysis Method) can also be utilised proactively for incident prevention as distinct from the more usual accident investigation. ICAM is also based on Reason's model.

3.5 A sociotechnical systems approach

Technical performance and the incidence of human error are influenced by organisational factors, including management decisions and safety culture, as well as external sociopolitical pressures (Reason, 1997).[23] Such influences within the system are determined by their proximity to the actual occurrence of error in the front line task or failure in a safety barrier, from the close to the most remote level.[24] Failure at different system levels is the key concept underpinning Reason's (1997) 'Swiss cheese' model and Trbojevic's (2008) sociotechnical systems pyramid (Figure 5).

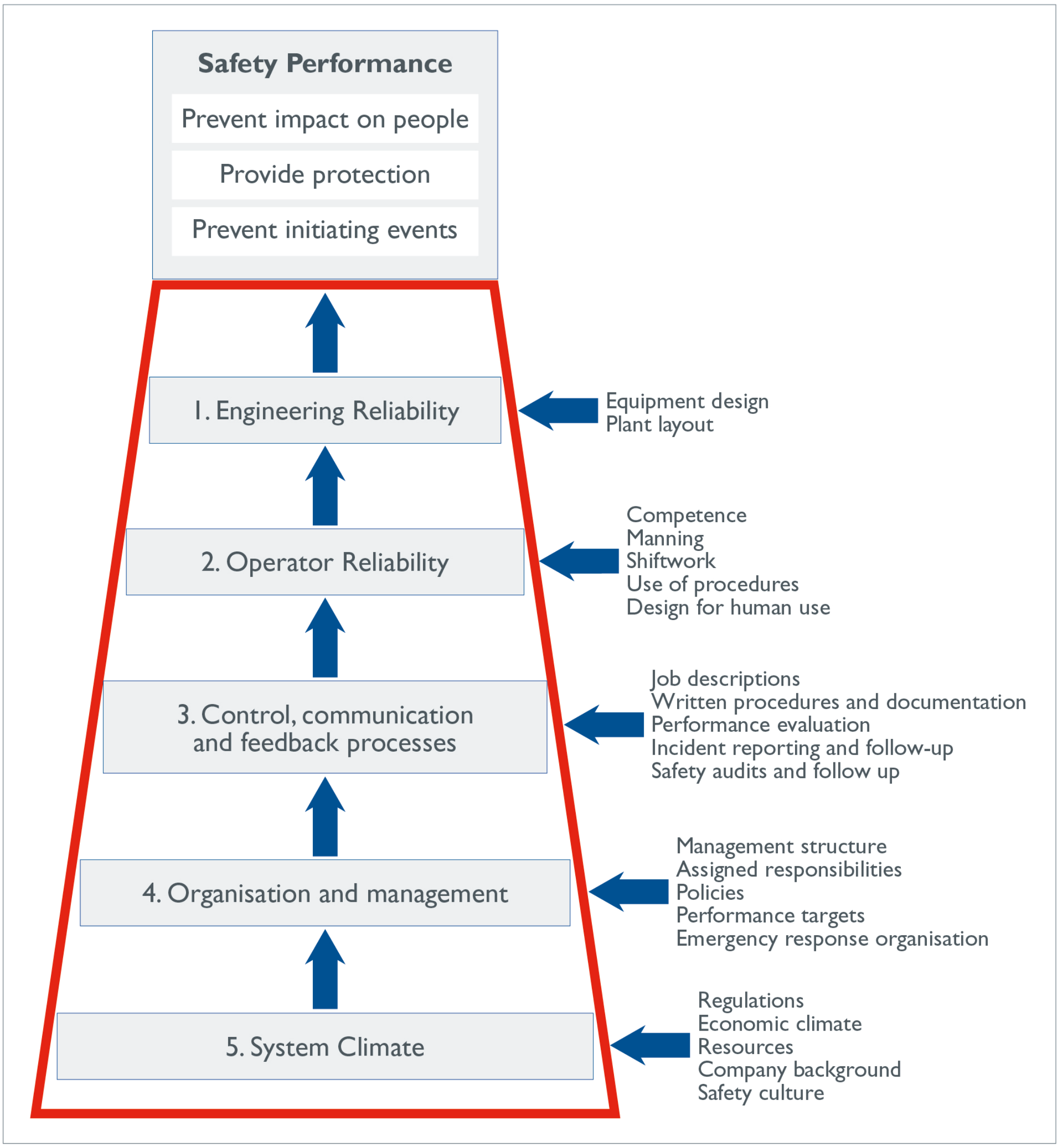

Figure 5: Sociotechnical systems pyramid (Modified from Trbojevic, 2008, p. 11)

[23] See also *OHS BoK* Organisational Culture.

[24] See *OHS BoK* Systems.

Trbojevic (2008, pp. 10–11) nominated five levels of influence on OHS performance:

> *Level 5: System climate or environment* – in which the organisation operates, including economic and regulatory requirements. External pressures affect the organisation and management needs to keep informed of relevant impacts and legislative changes. An organisation's safety culture is an important mechanism linking external forces to its approach to safety.
>
> *Level 4: Organisation and management* – includes structures, objectives, targets, strategies, etc., operating within the organisation. It defines safety policy and systems.
>
> *Level 3: Control, communication and feedback processes* – ensures that the system operates according to its intended goals, and identifies deviations from those goals, so that appropriate corrections can be made.
>
> *Level 2: Operator reliability* – covers the required competence (skills, knowledge and motivation) of staff to meet task demands imposed by technology, procedures and other external constraints. Competence and work demands need balancing.
>
> *Level 1: Engineering reliability* – refers to the design and maintenance of the plant or system.

Consistent with the work of Reason (1997, 2000), failures or human errors in the above system elements can be active or latent. Active failures/errors are felt immediately (e.g. a person inadvertently cutting into a live power line). Latent failures/errors (e.g. poor design, insufficient maintenance, inadequate training and supervision, or inappropriate procedures) are separated from their effects in time. Latent failures (also called latent conditions) can lie dormant until a set of circumstances (that may include an active failure or error) causes an accident. An extreme example of latent failure with a long dormant period was the 1992 fatal derailment that resulted from a flawed 1916 decision to lay rail tracks over a beaver dam in Nakina, Ontario (Reason, 1997).

Tripod Sigma[25] and similar proactive methodologies seek to identify such latent failures before any initiating event, and make such conditions visible to the workforce and managers through, among other things, the use of barriers. The extent of such latent failures can be interpreted as a measure of 'health' of the system (Trbojevic, 2008).

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[25] Another of the Tripod series, Tripod Sigma has been developed to identify general failure types that lead to psychosocial stressors within organisations. One study by Shell indicated that 42% of the variance related to job-related stress could be identified with work that was not efficiently organised, coordination problems and incompatible goals; these in turn were caused by problems with procedures, hardware, communications and training. See Nelemans et al., 2003, *Tripod Sigma*, APA/NIOSH Conference http://www.worldstp.com/WSP/Day%202%20-%207%20Oct%2003/Groeneweg%20Jop%20Article.pdf .

3.6 Precautionary principle

There will be situations where full or sufficient health and safety information on a hazard is unavailable. In such cases, the precautionary principle should be adopted. This principle states that:

> Where there are threats of serious or irreversible health or environmental damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental damage (ILGRA, 2002, p. 5).

An example of the application of the precautionary principle is the use of the control banding concept for nanoparticles. Originally proposed as an exposure-rating system to assist small and medium enterprises with control of hazardous chemicals exposure (Tijssen & Links, 2002), control banding has been identified as a viable tool for the assessment and management of nanoparticle exposures, for which the potential risks are not yet well characterised (Paik, Zalk & Swuste, 2008). This tool takes into account the estimated amount of the nanoparticles used, their 'dustiness/mistiness,' the number of employees with similar exposure, and the frequency and duration of the operation, to assess the risk of the operation and provide recommendations for control measures (Paik, Zalk & Swuste, 2008).

3.7 Critical risk controls strategies

The concept of process safety has been highlighted over recent decades following the organisational catastrophes such as those in relation to Piper Alpha (1988), Longford (1998), Texas City (2005), and Macondo (2010). While the concept may have resonated with operators of major hazard facilities, it is not widely utilised within the broader OHS profession.[26]

Hopkins (2009a) defines process safety hazards as those arising from the processing activity in which a plant may be engaged. Process safety is generally associated with the petrochemical and nuclear industry, but this is unnecessarily limiting. Most organisations utilise internal processes, and the way that the work process is set up can build in various hazards, consistent with Reason's latent conditions (Reason, 1997). Process safety can be understood by discussing some of the indicators that could be used to determine the safety of the process. Loss of containment of hazardous or flammable substance was highlighted as critical in the Texas City disaster. However, moving away from petrochemicals, Hopkins (2009b) identifies process safety indicators in aviation as loss of separation between aircraft. Process safety indicators within other industries could include the rate of re-infection (hospitals); driver fatigue (road transport) and so on.

[26] See *OHS BoK* Managing Process Safety for a discussion on process safety.

The international mining and metals industry is currently adopting a systematic use of process safety controls (ICMM, 2015), using a concept developed by the Health & Safety Executive (UK) for the chemical and major hazard industries (HSE, 2006). This concept identifies specific risk control systems, used to describe a constituent part of a process safety management system that focuses on a specific risk or activity, e.g. plant and process change, permit to work, inspection and maintenance, etc. The proper operation of these critical risk control systems is seen as essential for the safe operation of the process / plant. Failure of the permit to work system was seen as instrumental to the Piper Alpha disaster. HSE have then developed a dual set of leading and lagging performance indicators (dual assurance) that check to see that the key risk control systems are operating as intended, but also to provide warnings that problems are starting to develop through a degradation of the control, before these problems become destructive and control of the process is lost (HSE, 2006).

It is up to the organisation in a process risk assessment to identify critical risks. The International Council on Mining and Metals identify examples that include diesel emission control of underground plant (ICMM, 2015). The ICMM denote the risk control systems found within mining and minerals processing as 'critical controls'. These are controls that are crucial to preventing the top event or mitigating the consequences of the event. They have developed a formalised process from planning, through performance reporting, implementation and verification. Process causes that can lead to an unwanted top event are identified through a bow tie analysis, and then critical controls identified for both the prevention and mitigation sides of the bow tie. Leading and lagging indicators for each critical risk are developed with assigned responsibilities for ownership, action and reporting. The requirement that the required performance can be specified and verified is crucial to the critical control concept. It also links into the accident investigation process to determine the adequacy of the controls.

Australian mining legislation require mine operators to develop safety management systems, so the concepts of critical controls, together with appropriate performance indicators links well with this requirement and allows the manager to include the critical controls within their safety system. This is a useful model for other industries to review for application within their safety management systems.

An important qualification would be that the formal nature of the ICMM approach could easily result in a 'tick the box' system where the reporting process becomes the end rather than the means, and the actual objective of improving process safety is lost. ICMM (2015) recommends that before considering implementation, organisations need to assess their level of safety maturity, and particularly whether the senior management has total buy-in for its implementation and operation.

A final comment is that, as noted in 3.2 above, trying to identify every possible state of variety in a complex process may not be possible. Mining is identified by Perrow (1984) as having loose coupling and moderate complexity, so that there may be success in identifying the common hazards in mining and metals processing. However, regardless of the coupling / complexity state of a process, it is important to have competent operators who are trained to constantly and critically review the process to be able to be the final barrier to controlling the process, if unexpected circumstances arise (see Trbojevic, 2008; Hollnagel, 2008).

3.8 Safe design

Designing safety into plant, equipment and structures is a priority within OHS legislation[27] because such 'upstream' control action greatly simplifies safety management in the use of that plant, equipment or structure. An extensive discussion on safe design is provided in *OHS BoK,* A User-centred, Safe Design Approach to Control and in *OHS BoK*, Engineered Safe Design.

3.9 Behavioural-based safety

The administrative control of behavioural-based safety is still used in many workplaces as a risk-control program. Behaviour based safety is largely based on the 'safe-person' concept and is used in US organisations. Of relevance is Manuele's (2006, p. 185) observation that many behavior-based safety consultants "have largely ignored the necessity of making hazards analyses and risk assessments and the application of a hierarchy of controls in the preventive measures they propose;" rather, they have promoted a form of occupational psychology focused on the worker as the solution to injury problems.

As noted in the earlier discussion on safe person vs safe place, behavioural controls can form a legitimate control option within an organisation. However, behavioural controls have to be utilized appropriately. Hudson (2007) identifies behaviours as one intervention in the *third* (and final) step of improving the safety culture of an organisation that can be applied when the organisation has already made great progress in safety. The first two steps are legislative compliance, where the employer ensures safe equipment and engineering; followed in the second step by implementing safety management systems that apply risk management principles and ensure competent staff. He identifies the difficulties in altering organisational processes and behaviours across large organisations. This is consistent with the conclusions of Fleming and Lardner (2002, p.i), who after reviewing literature on behaviour-based programs, commented:

[27] For example, see Division 3 of the model Work Health and Safety Act which identifies duties of designers, manufacturers, etc to provide safety plant and structures (SWA, 2016a).

> Whilst a focus on changing unsafe behaviour into safe behaviour is appropriate, this should not deflect attention from also analysing why people behave unsafely. To focus solely on changing individual behaviour without considering necessary changes to how people are organised, managed, motivated, rewarded and to their physical work environment, tools and equipment, can result in treating the symptom only, without addressing the root causes of unsafe behaviour.

Fleming and Lardner (2002, p. 22) identified two management behaviours that are critical for effective safety leadership: "meeting with employees frequently to discuss safety issues [and] responding quickly to safety suggestions and concerns raised by employees." Hopkins (2002) suggested that a variant of behaviour modification – "the promotion of risk awareness within the workforce" (e.g. use of 'Take 5' or similar programs) – may have value in developing individual mindfulness, but only if such action is part of a broader strategy to develop organisational or collective mindfulness.

Weick, Sutcliffe and Obstfeld (2008) place collective mindfulness as a central pillar of high reliability theory, which is about the quality, not just quantity of attention, with the workers acting on what they see. There is sharing of information. Employees have been inculcated by the organisation to understand that the organisation is willing to act and authorises them to act to control hazards. Clearly this is more than merely checking if correct behavior (e.g. wearing PPE) is being undertaken, which the more common approach of behaviour-based observations.

In summary, behavioural controls may be useful provided that all higher-order preventative measures (e.g. substitution and engineering controls) have been implemented, and that organisational and system causes of accidents have been identified. Based on the work of Reason and others, the 'Hearts and Minds' approach developed for the UK petrochemical industry is an example of a program that incorporates behaviorual controls as the end step *after* management accountability, engineering controls, legislative compliance, OHS systems and operator training have been implemented (see Energy Institute, n.d.). Behavioural controls should never be utilised in lieu of the more effective control methods discussed above.

4 Regulatory requirements

The way an organisation goes about controlling risks is influenced by its safety culture and the regulatory environment in which it works. While legislation mandates minimum requirements for compliance, organisations with a strong safety culture generally aspire to more than minimum compliance (Parker, Lawrie & Hudson, 2006).

The *Work Health and Safety Act* (SWA, 2016a) requires that:

> (1) A person conducting a business or undertaking must ensure, so far as is reasonably practicable, the health and safety of:
> (a) workers engaged, or caused to be engaged by the person; and

> (b) workers whose activities in carrying out work are influenced or directed by the person, while the workers are at work in the business or undertaking.
> (2) A person conducting a business or undertaking must ensure, so far as is reasonably practicable, that the health and safety of other persons is not put at risk from work carried out as part of the conduct of the business or undertaking. (WHSA s 19).

Determining what constitutes 'reasonably practicable'[28] is considered to be an objective test taking account of:

> …that which is, or was at a particular time, reasonably able to be done to ensure health and safety, taking into account and weighing up all relevant matters including:
> (a) the likelihood of the hazard or the risk concerned occurring
> (b) the degree of harm that might result from the hazard or the risk
> (c) what the person concerned knows, or ought reasonably to know, about the hazard or risk, and ways of eliminating or minimising the risk
> (d) the availability and suitability of ways to eliminate or minimise the risk, and
> (e) after assessing the extent of the risk and the available ways of eliminating or minimising the risk, the cost associated with available ways of eliminating or minimising the risk, including whether the cost is grossly disproportionate to the risk. (WHSA s 18)

The concept of barrier decay (section 3.3) also should be considered in determining what is reasonably practicable. While a control may be effective when implemented, both hardware (e.g. mechanical barriers) and software (e.g. procedures) can degrade over time unless periodically reviewed and updated. According to Manuele (2006, p. 189), "No matter how effective the risk reduction measures taken, if an activity continues there will always be residual risk. Residual risk is defined as the risk remaining after preventative measures have been taken." A residual risk register should be maintained, and all risk controls regularly reviewed to counter barrier decay, and to account for system changes and/or new information. This monitoring is a key stage in all risk-management models[29] and is specifically included in the *How to Manage Work Health and Safety Risks: Code of Practice* (SWA, 2011a).

The *WHSA* (s 17) defines how risk is to be treated:

> A duty imposed on a person to ensure health and safety requires the person:
> (a) to eliminate risks to health and safety, so far as is reasonably practicable; and
> (b) if it is not reasonably practicable to eliminate risks to health and safety, to minimise those risks so far as is reasonably practicable (Safe Work Australia, 2011b).

The *Model Work Health and Safety Regulations* (Safe Work Australia, 2016b) specify requirements for control of particular hazards; for example, noise (s 4.1.2), manual handling (s 4.2.4), falls (s 4.4.3), electrical work (s 4.7.7), plant (s 5.1) and chemicals (s 7.1.32). As a condition of their operating license, Major Hazards Facilities are required to develop and maintain a 'Safety Case,' which identifies all the significant risks within the

[28] 'Reasonably practicable' is also extensively discussed in *OHS BoK* Principles of WHS law. See also SWA, 2011b.
[29] See *OHS BoK* Risk.

facilities, and then show how those risks will be controlled to a degree of risk acceptability defined within the Safety Case (SWA, 2016b)

Other legislation addressing specific risk controls includes:

- Mining regulations require the use of safety management systems to comprehensively control all underground mining risks, and to put in place systems to control the adverse effects of drugs and alcohol[30]
- Road regulations require 'chain-of-responsibility' systems to manage fatigue in long-haul drivers (NTC, 2006)
- Radiation safety legislation requires licensed users of radiation to consider a 'radiation safety principle' where any use of radiation is questioned (i.e. with emphasis on elimination); however, if the use is justified, then exposure is kept as low as reasonably achievable (ALARA).[31]

5 Implications for OHS practice – Designing control strategies

Modern accident prevention may have started with Heinrich's 1931 seminal work, but not all the actions that OHS professionals have implemented over the intervening years have been based on evidence, nor have been even useful. One approach popular in the 1980s, loosely based on Heinrich's work was the concept that controlling near misses and minor accidents would lead to a reduction of major accidents and fatalities. Hale (2002) clarified this urban myth by identifying that this works only if you are analysing the same hazard class in terms of minor and major accidents. It should have been obvious that reducing the slips, trips and falls in an organisation has no relation to preventing explosions or driving fatalities. Indeed, Hopkins (2009a) identifies examples of disasters such as BP (Texas City, Macondo) and Esso (Longford) that focused on reducing LTIFR to the exclusion of having controls that reduced the major hazard risk. These examples should highlight that OHS professionals need to argue that evidence-based approaches are needed, and not safety fads that may appear from time to time.

Much current OHS theory, including barrier theory and critical risk controls evolved from research in high-risk industries, including nuclear and petrochemicals (e.g. Reason, 1997; Parker, Lawrie & Hudson, 2006) While this may be perceived as overly complex for many 'normal' industrial situations, the OHS professional is cautioned against assuming that development and maintenance of a safe workplace is inherently simple or that a risk-free workplace can be achieved simply through application of the hierarchy of control or behavioural-based safety.

[30] For example, see s 9.3.2 in the *Model Work Health and Safety Regulations: Chapter 9 – Mines* (SWA, 2016b).
[31] See *OHS BoK* Physical Hazards: Radiation.

While the controls relating to individual hazards may be simple and well known, the overall organisational work system is inherently complex and is constantly changing. One simple example that is occurring in many workplaces is the increased use of casual, contract or labour-hire workers alongside employees. This greatly complicates communications, supervision and competency and is consistent with what Weick, Sutcliffe and Obsrfeld (2008, p.34) note that "all organisations, because of interconnected technologies and interconnected resource demands are moving toward an interactively complex tightly coupled state". This complexity is reflected in the introductory paragraph for the chapter which references just some of the OHS Body of Knowledge chapters.

A risk-free workplace is not possible (Hollnagel, 2008), although may remain an aspirational goal. Objectives of 'zero-harm' should be treated in this manner. Indeed, Hudson (2010) described health and safety practice as "more complex than rocket science." It is not simply a case of 'fixing' the hazard (e.g. noise, manual handling, etc.), but of understanding how and why the risk exists as a result of interaction between the hazard, the organisation, the people and the particular job.

Designing appropriate control strategies has to take these issues into account, and also consider the size and profitability of the organisation, as well as the safety maturity level of the organisation. What is suitable for a multi-national, may not be appropriate for a small business, and what may be appropriate controls for an organisation at a reactive maturity level will be insufficient for one at the proactive stage.[32] Townsend (2013) discusses the appropriate control systems for organisations as they increase in size and maturity, and notes that as organisations improve their safety systems, the type of accidents that they need to control changes. Control strategies have to be dynamic and adapted to the organisation during all stages of its life cycle.

Tepe and Barton (2009) argue that OHS professionals need to be able to use a range of system views to suit the complexity of any situation. The sociotechnical model is promoted as a useful tool as it is consistent with the work of Reason (1997) and with ergonomic principles that address risks in the context of the user, job/task demands, work environment, equipment design and work organisation.[33] The OHS professional should search for process weaknesses by utilising latent failure analysis (e.g. Tripod Beta or similar) and be prepared to apply multiple barriers or controls (requisite variety). Also, they should be cognisant of the potential for barriers to decay, and consider counterbalancing primary barriers with secondary barriers, including system reviews and audits, as necessary components of their OHS management system.

The appropriate level or variety of control to be applied is that which matches the variety of the situation. For 'simple' situations such as working at heights, good results can be

[32] See Parker D., et al. (2006) for a discussion on safety maturity levels.
[33] See *OHS BoK* A User-centred, Safe Design Approach to Control and *OHS BoK* Engineered Safe Design.

consistently obtained by following legislated guidelines for such work. In addition, if an organisation has low safety maturity and does not have safety systems or processes in place, then traditional approaches of training workers and supervisors, assessing risk and providing basic controls will provide significantly improved safety outcomes (Townsend, 2013).

Conversely, where organisational processes are complex and tightly coupled, then the simple approaches are no longer sufficient and higher order systems-based models need to be applied. Examples of such tightly coupled, complex systems in Australia would include control of the electrical power network across the eastern seaboard, or control of petrochemical complexes such as Longford. Higher order, systems based models include the Functional Resonance Accident Model (FRAM) and the Systems-Theoretic Accident Model and Processes (STAMP). (See Hovden, Albrechtsen and Herrera (2010).

Successful control of risk requires an in-depth understanding of hazards and the physical, organisation and psychosocial environments, together with an understanding of the psychological principles that explain behaviour of workers as individuals and in groups. This requires the OHS professional to seek a 'richness' of information to identify and understand the risks (Weick, 2007). Weick (2007, p.18) argued "for detail, for thoroughness, for prototypical narratives, and…against formulations that strip out most of what matters." Risk assessment is more than filling in a checklist or consulting a risk matrix. After gathering the necessary information to maximise their understanding of risk, OHS professionals need to take a pluralist approach to application of appropriate principles and theoretical model(s) to structure rigorous control systems for the prevention of injury (Tepe & Barton, 2009).

The effectiveness of control will be limited by an organisation's safety maturity, which impacts on the management decisions relating to the types and quantities of controls that are implemented. The OHS professional needs to identify the safety maturity of the organisation to know what appropriate control strategy can be applied, which in most cases will not be 'best practice'.[34] At the very minimum, organisations need to comply with relevant legislation. Where a code of practice or guidance note has been published by a regulator on a topic, the control measures described therein will be deemed as 'reasonably practicable' for the purposes of complying with legislation. However, such a limited perspective generally means that OHS remains an 'add-on' to operations. Typically, organisations with excellent OHS records have moved beyond mere compliance and integrated OHS into their ordinary operations. OHS professionals need to develop strategies to increase the maturity levels of the organisation so as to achieve effective control of risks at work. This integrates OHS into the operations and moves towards 'best practice'. They have to become organisational change agents, which is a key strategic skill.

[34] See *OHS BoK* The Organisation.

Clearly, OHS professionals have to monitor the effectiveness of any control strategy implemented. Has it improved safety outcomes, or had no significant impact? This requires that measures of effectiveness or performance measures are included into the design of the control strategy. Where possible, such measures should be quantified in monetary or statistical terms, which is the main language of management and essential if management is to be convinced to change and accept that ‘safety is the way we do things around here’.

6 Summary

The causation of work-related fatality, injury, disease and ill-health may be simple in some situations but generally is complex. Control strategies need to be comprehensive to address the complexity of the process. Approaches to control need to move beyond a simplistic application of the hierarchy of control to consider strategies required in the pre-conditions, occurrence and consequence phases. The development of such strategies should be informed by knowledge of barriers and defences, and how they may break down or be breached. Sociotechnical system models (e.g. Reason’s ‘Swiss cheese’ model) provide a broad-based approach that addresses the requisite variety of strategies to address the complexity of causation. Tightly coupled, complex process systems may require more complex models. OHS professionals should remain vigilant in ensuring that their advice is informed by current OHS knowledge, but not allow a lack of full scientific certainty to excuse lack of action when there is threat of serious injury or health outcome. Providing advice on appropriate risk control strategies is the fundamental reason for an OHS professional to be in a workplace.

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