Centre for
Construction Work Health and Safety Research

Applying the hierarchy of control to occupational health risks in construction: Barriers to effective decision-making

Literature Review

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About the Centre for Construction Work Health and Safety Research

The Centre for Construction Work Health and Safety Research provides leading-edge, applied research to the construction and property industries. Our members are able to work with organisations to analyse health and safety (H&S) performance and identify opportunities for improvement. We can develop and evaluate innovative solutions, provide specialised H&S programs or undertake other research-based consulting activities. Our work addresses real-world H&S challenges and our strong international linkages provide a global perspective to our research.

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Part 1: Executive summary

In Australia, Work Health and Safety (WHS) legislation has been described as process based to the extent that it requires duty holders to reduce risk so far as is reasonably practicable. In order to fulfil this duty, organisations need to implement management processes to identify WHS hazards, assess risks presented by these hazards, decide how to control the risks and implement and monitor the selected control measures.

Underpinning the selection of WHS risk controls is a hierarchy of control, which categorises controls into three levels based on their effectiveness. Level one controls eliminate a hazard altogether. Level two controls act on the work environment to make it physically safer, while level three controls rely for their effectiveness on human behaviour, such as administrative measures and the use of personal protective equipment. By law, duty holders need to implement level one and two controls as a matter of priority and, only when it is not reasonably practicable to implement these, should level three controls be selected.

Relative to safety hazards, far less attention has been paid by researchers to the control of work-related health hazards in the construction industry. Researchers also note a common confusion between organisations' fulfilment of their legal duty to control occupational health hazards and the adoption of more general health and wellbeing initiatives focused on so-called 'lifestyle' health factors.

The literature review revealed a range of controls available for work health hazards identified as relevant to the construction industry. These controls were classified according to five levels of the risk control hierarchy in descending order of effectiveness, namely:

- elimination
- substitution
- engineering
- administrative, and
- personal protective equipment.

The literature revealed little research has been undertaken investigating the factors that influence the selection and effectiveness of risk controls for occupational health hazards relevant to construction work.

However, research has examined decision-making in relation to WHS more generally. A number of factors have been identified as relevant to decisions that are made and the quality and effectiveness of risk control measures that are implemented. These include organisational/structural factors, individual/psychological factors and social/cultural factors.

Organisational/structural factors influencing the selection of WHS risk controls measures include the timing of decision-making and the extent to which people with knowledge of construction processes, methods and technologies are present when decisions are made. Research suggests that the consideration of WHS early in the construction project life cycle and the availability of construction process knowledge to decision-makers improved decision-making and increases the likelihood that level one and two risk controls will be selected. The concept of designing for construction workers safety is now reasonably well established but the review suggests that designing for construction workers' health is also important yet is much less well established.

Complexity on the construction supply chain is also identified as a barrier to the selection and implementation of the most effective controls for WHS risk, as important information often resides with specialist sub-contractors who may not be involved in the project when important decisions are made. Competitive sub-contracting practices can also militate against the implementation of high level risk controls.

Many different stakeholders influence and make decisions over the life of a construction project, each with varying levels of knowledge and interest in managing occupational health risks. Research suggests that some parties who contribute to or influence decisions may not be aware of their impacts on workers' health or safety.

Research also reveals inherent biases in the way that people perceive risk, such that acute effect safety risks tend to be perceived as being more severe than health risks that are perceived to be less certain and/or to have a delayed effect. The tendency to underestimate health risks relative to safety risks is likely to act as a barrier to the implementation of level one and two controls for occupational health risk, even though the long term consequences of exposures to occupational health risks are known to be serious and significant.

Theories of behaviour change may also apply to decision-makers who may not be aware of level one and two risk controls or want to or be able to implement these controls. Understanding decision-makers' motivation in relation to the selection of high level controls is important for occupational health risks in construction projects.

The hyper-masculine social/cultural context of construction projects is also identified as an impediment to the effective management of occupational health risks. Research reveals an acceptance of poor health as an inevitable part of working in the construction industry, as workers feel disempowered and unable to effect change, despite being concerned about their health.

Understanding the factors influencing the quality of risk control for occupational health risks is important in order to remove constraints and create project conditions that enable the selection and implementation of effective controls for occupational health risks. The extent to which barriers identified in the literature review apply to the selection and implementation of level one and two controls for occupational health risks in the Australian construction context is not known.

Part 2: Introduction

What are the barriers to implementing the hierarchy of control to reduce health risks?

The construction industry is often cast as a demanding and dangerous industry in which to work. The construction workforce is exposed to a wide range of occupational health hazards, arising from the physical work environment, the design of work tasks, materials and chemicals in common use and the psychosocial work environment.

Non-managerial (manual) construction work is physically demanding and the incidences of physical injury and work disability are high. Many construction workers suffer from permanent work incapacity and are forced to stop working due to health problems before they reach the statutory pension age (Brenner & Ahern, 2000). In Germany, up to 63% of construction workers retire early due to permanent disability (Siebert et al. 2001).

Construction workers are exposed to a wide array of hazardous physical working conditions, including manual handling and exposure to vibration, noise, chemicals and dust (Snashall, 2005; Stocks et al., 2011; Jaafar et al., 2017). International studies show that rates of occupational illness are high among construction workers. For example, Stocks et al. (2011) analysed instances of medically reported work-related ill health among construction workers in the United Kingdom and found elevated rates of contact dermatitis, all types of skin neoplasma, non-malignant pleural mesothelioma, lung cancer, pneumoconiosis and musculoskeletal disorders.

A great deal of effort and energy is put into the reduction of work-related injury and fatalities, with far less focus placed on occupational ill-health and disease (Lamont, 2010). However, given the prevalence of occupational illness in the construction industry, progressive construction clients and organisations are beginning to focus more attention on the prevention of work-related illness and disease (Sherratt, 2015).

Sherratt (2015) observes that legislation in the UK (and also in Australia) bundles occupational health and safety together, which she sees as being unhelpful because health is a very different concept to safety and therefore health needs its own parameters and management approach. Unlike safety, which occurs at the site, at a fixed point in time, health occurs over extended periods and is not specific to the worksite. Sherratt (2015) argues that work health and safety management approaches (including the application of the risk control hierarchy), have not effectively controlled hazards that impact construction workers' health. Further, there is confusion between the legal obligation of employers to reduce occupational health risk exposures so far as reasonably practicable and the current implementation of health promotion programs targeting so-called lifestyle risk factors, such as alcohol consumption, smoking cessation, diet and physical activity. While programs designed to improve workers' lifestyle behaviours may produce benefits, their implementation does not remove the legal duty of employers to reduce exposure to known occupational health risk factors.

This literature review focuses on the Australian construction industry and health hazards that are potentially present during tunnelling and demolition tasks. The objectives of this literature review are to:

- identify and evaluate evidence supporting the implementation of the control hierarchy in construction project environment(s) to prevent occupational illness; and
- identify future research opportunities that identify and characterise factors which influence decision making when controlling and preventing prevent occupational illness in the construction industry.

The literature review forms the basis for the development of further steps through which the research will be conducted. The literature review will inform the further development of a research approach designed to:

- identify factors that influence decision-making relevant to prioritising the control of hazards that cause occupational illness in construction workers
- determine the potential barriers that prevent the selection and implementation of controls, higher in the control hierarchy to reduce occupational illness in the construction industry, and
- identify and characterise factors which influence decision making when controlling and preventing occupational illness in the construction industry.

This literature review has two components.

- The first component explores the barriers to the implementation of high-level (technology-based) control measures for occupational health risks in the construction industry, and
- the second component identifies measures that can be used to control the risks posed by selected occupational health hazards relevant to construction work. These measures are detailed in the Appendix.

Part 3: Methodology

A systematic review of the literature was carried out in order to:

- identify control measures for each relevant hazard
- establish the effectiveness of these control measures
- identify factors that influence decision making in order to prioritise and implement these control measures, and
- determine barriers that potentially prevent the selection and the implementation of these controls.

A systematic search for literature was undertaken using the databases: Science Direct, Scopus, Taylor & Francis, Pro Quest and the American Society of Civil Engineers.

In addition, the following journals were included in the search: American Journal of Industrial Medicine, Occupational and Environmental Medicine, Journal of Occupational Health Psychology, Social Science & Medicine, Occupational Medicine, Annals of Work Exposures and Health and the American Industrial Hygiene Association Journal.

Grey literature relating to the subject was examined, including: the Australian Bureau of Statistics, the Health and Safety Executive (UK), Workplace Health and Safety Queensland, the Yale Environmental Health & Safety, the German Federal Agency for Industrial Health & Safety, German accident insurance institutions, German institutions for statutory accident Insurance and prevention, the Laborers' Health and Safety Fund of North America, the Occupational Health and Safety Administration (USA), the National Institute for Occupational Safety and Health (USA) and Safe Work Australia.

The search strategy utilised a combination of key words and strings. The Boolean operators "and" and "or" were used while looking for studies / reports in English, German or a Scandinavian language. Studies eligible for inclusion included reports, studies or web-based guidance materials that were associated with construction, tunnelling, demolition works, decision-making, controlling health risks or risk perception.

The selection of studies was carried out in two stages. First, studies were included based on their title and abstracts. Second, studies with content that was not linked with the construction industry or the decision making process or barriers or studies which were too specific to be transferred to the construction industry were excluded to a number of 350 eligible studies.

Part 4: Research context

4.1 Australian construction industry

The scope of the construction industry, as defined by the Australian Bureau of Statistics (2015), includes the construction, addition, alteration, reconstruction, installation, maintenance, repair, demolition or wrecking of buildings and other structures. Such activities also include the clearing of building sites, blasting, test drilling, landfill, levelling, earthmoving, excavating, land drainage and other land preparation activities.

In 2015-2016, the Australian construction industry contributed $134.2 billion to Australia's GDP, equating to 8.1% of total output value and subsequently placing construction as the second highest contributing industry to the Australian economy.

The Australian Bureau of Statistics (2010) report that the Australian construction industry is not only one of the largest, it is one of the most important Australian industries, citing movement in economic industry indicators associated with the construction of building, residential, non-residential and major engineering projects to be linked directly to changes in social, economic and political trends.

To service the Australian construction industry and its economic contribution approximately 1,111,000 persons, or 9.8% of the Australian working population are employed, representing Australia's third largest contributor to employment, with the largest number employed in NSW (211,000) followed by Victoria (177,700) and Queensland (145,700). According to the Department of Industry, Innovation and Science (2016) "construction growth is solid", however a distinct national pattern demonstrates such continued growth only to be observed in NSW and Victoria, while all other states continue to demonstrate a decline. Of particular note, construction in NSW is considered in the economic context to be exceptionally strong, with significant building construction in association with major infrastructure projects such as Westconnex, Northconnex, Sydney Metro, Sydney Light Rail and Princess Highway upgrades in metropolitan Sydney.

While it is good to consider and commend the economic gain afforded by the Australian construction industry, it should be noted that such performance is not without consequence to those personnel working in and servicing such an industry. Fundamentally, while profits are being made and persons are being employed, such persons are experiencing occupational injury and disease at rates, and with consequences that far exceed any moral boundary. For purposes of economic comparison Safe Work Australia (2015a) estimated for the 2012-2013 financial year the total economic cost associated with work-related disease and injury was $61.8 billion, representing 4.1% of GDP for the same reporting period. Unsurprisingly, the construction industry ranked as the third highest contributor to such economic burden, equating to costs of $5.84 billion, of which occupational disease contributed $2.98 billion, or 51%.

In more human and less economic terms, statistics released by Safe Work Australia (2012) demonstrate each year on average 250 workers will die from an injury sustained at work, while over 2000 workers will die from an occupational disease. And whilst occupational health and safety policies and systems are inherently focused on safety, all too often there is a failure to adequately focus on work-related health hazards. Such failures are frequently linked to the specific challenges associated with managing occupational health risks, particularly as such hazards can be invisible, silent and insidious in the long latency of their ill effects, with health problems only emerging many years later.

Such statistics and realised shortfalls prompted Safe Work Australia to review the performance of work, health and safety among all Australian industries. The review identified the construction industry's inherent hazardous nature results in one of the highest incidence rates and highest number of workers' compensation claims when compared to all other industries. As such, in 2012 Safe Work Australia (2012) nominated construction as a priority industry for improved performance, with a particular focus on preventing the following high prevalence occupational diseases:

- musculoskeletal disorders
- mental disorders
- cancers (including skin cancer)
- asthma
- contact dermatitis, and
- noise-induced hearing loss.

4.2 Legislative requirements

In July 2008, the Council of Australian Governments (COAG) signed an Intergovernmental Agreement (IGA) formalising the cooperation between the Commonwealth, State and Territory governments to achieve harmonisation of Work Health and Safety Law (Safe Work Australia 2017). Since such time, all jurisdictions have implemented the model WHS laws with the exception of Victoria and Western Australia[1].

Safe Work Australia is the national policy body responsible for developing and evaluating work health and safety laws, while the Commonwealth, States and Territories are responsible for regulating and enforcing these laws in their respective jurisdictions.

The principle Object of the WHS Act (Australian Government, 2017a) is to provide a "framework to secure the health and safety of workers and workplaces" (Safe Work Australia 2016a, p.5) by requiring duty holders to eliminate or minimise risk to protect workers and other persons from harm, and extends the object to risk management through the application of the overriding principle that "workers and other persons should, so far as is reasonably practicable, be given the highest level of protection against harm to their health, safety and welfare from hazards and risks arising from work" (Safe Work Australia 2016a, p.5).

1 At the time of writing the Western Australia Government was conducting consultation on options to implement elements of the model WHS Regulations.

4.2.1 Highest level of protection

The concept of affording workers and other persons *"the highest level of protection"* is founded on the principle that risks will be eliminated. However, in the context of the workplace, achieving such an obligation is only required by duty holders where it is reasonably practicable to do so (Australian Government, 2017b). As such, and in circumstances where risks to health and safety are not eliminated, duty holders must minimise such risks by performing the following, in the following order:

- substituting (wholly or partly) the hazard giving rise to the risk with something that gives rise to a lesser risk
- isolating the hazard from any person exposed to it, and
- implementing engineering controls.

In circumstances where a risk continues to remain, the duty holder must minimise the remaining risk, so far as is reasonably practicable, by implementing administrative controls.

Following the implementation of administrative controls and where a risk remains the duty holder must minimise the remaining risk, so far as is reasonably practicable, by ensuring the provision and use of suitable personal protective equipment.

The New South Wales Work Health and Safety Regulations (New South Wales Government, 2018) require persons conducting a business or undertaking (PCBUs) at a workplace must ensure that no person at the workplace is exposed to a substance or mixture in an airborne concentration that exceeds the exposure standard for the substance or mixture (regulation 49).Further, under regulation 50, PCBUs must ensure that air monitoring is carried out to determine the airborne concentration of a substance or mixture at the workplace to which an exposure standard applies if:

(a) the person is not certain on reasonable grounds whether or not the airborne concentration of the substance or mixture at the workplace exceeds the relevant exposure standard, or
(b) monitoring is necessary to determine whether there is a risk to health.

The results of this monitoring need to be recorded and kept for 30 years. Exposure standards exist for a variety of airborne contaminants present in construction work. Exposure standards for crystalline silica are expressed as a time-weighted average value of 0.1 mg/m^{3}. This means that the maximum average airborne concentration of a substance when calculated over an eight-hour working day, for a five-day working week should not exceed this amount.

However, where workers have a working day longer than eight hours or work more than 40 hours a week, PCBUs must determine whether the time weighted average exposure standard needs to be adjusted to compensate for greater exposure during the longer work shifts, as well as decreased recovery time between shifts (Safe Work Australia, 2018a).

The expression of exposure standards as a time weighted average value presents challenges for exposure monitoring and application of standards in construction as workers can often work shifts longer than 8 hours and the average weekly work hours of site-based workers typically exceed 40 (Lingard & Francis, 2004). By their nature, construction project environments are constantly changing, which could potentially impact on the reliability and effectiveness of monitoring.

The above described risk control methodology is what is known as the Hierarchy of control and extends to include a combination of controls where a single control is not sufficient for minimising the remaining risk, so far as is reasonably practicable.

4.2.2 Hierarchy of control measures

The concept of the control hierarchy originated in the US National Safety Council's in 1955, publication "*Accident Prevention Manual for Industrial Operations".* Under the title of "Removing the Hazard from the Job" a three-tiered control hierarchy was introduced in the following order of effectiveness and preference:

1. elimination of the hazard from the machine, method, material, or plant structure
2. guarding or otherwise minimizing the hazard at its source if the hazard cannot be eliminated, and
3. guarding the person of the operator through the use of personal protective equipment if the hazard cannot be eliminated or guarded at its source". (National Safety Council, 1955, cited in Manuele 2008, p.204).

The application of the above risk reduction framework was considered an advancement of health and safety practice as it afforded decision makers a systematic method of prioritising controls to achieve greater reductions of risk, hence, the formation of what we now know as the "Hierarchy of Control" (HoC), which over time has evolved to suit the nature and context in which it has been applied (Manuele, 2008).

The HoC arranges occupational health (and safety) risk control measures in order of their effectiveness.

"Control Measure" as defined in the Work Health and Safety Regulation is "a measure to eliminate or minimise" risk (Australian Government, 2017b, Chapter 1, Part 1.1)

The HoC is based on the principle that making the work environment physically safer and healthier is more effective than changing the behaviour of workers.

The HoC classifies ways of dealing with occupational hazards/risks according to the level of effectiveness of the control. The HoC is depicted in Figure 1 using control measures for diesel engine exhaust emissions to illustrate each of the levels.

The top three layers of control may be classed as technological controls, or upper level controls, because they change the physical work environment and work procedures. In contrast, the bottom two elements, lower level controls, represent behavioural controls that seek to change the way people work.

In selecting methods to reduce the risk of occupational injuries or ill-health, decision-makers must first understand all of the available control methods that could be implemented and then start from the top of the hierarchy and work down, ensuring that they select the highest level of control measure that can be implemented.

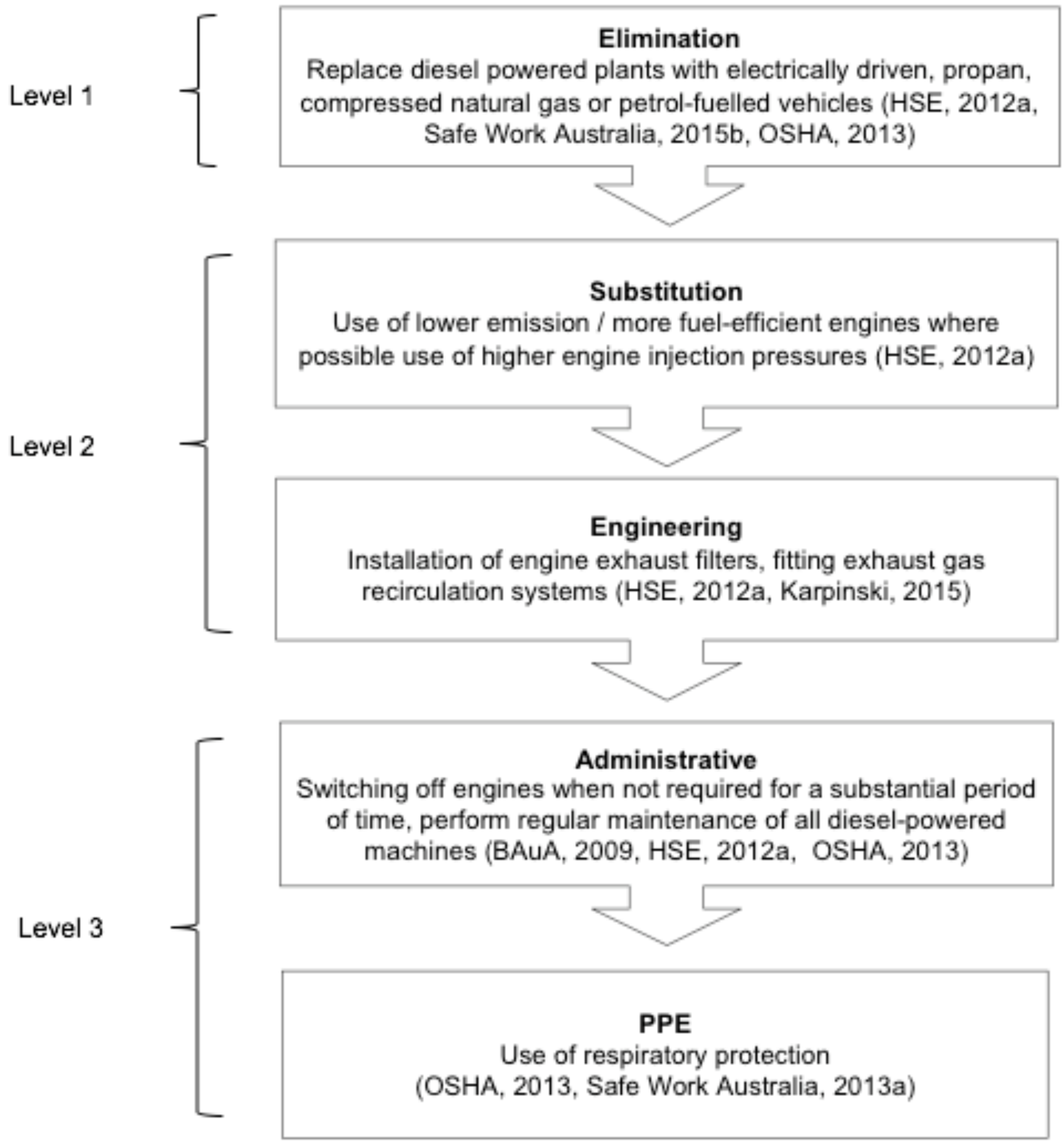

Figure 1: Hierarchy of controls.

In the context of Australian Work Health and Safety legislation, Regulation 36 requires duty holders to prioritise Level 1 controls, followed by Level 2 controls, then and only in circumstances where Level 1 and 2 controls are not reasonably practicable, apply Level 3 control(s). Applying the HoC to prevent or mitigate occupational health hazards in construction work environments principally relies on rational decision making which is performed in a ranked and sequential order. In order to achieve this, decision makers must regard the purpose and achievement of goals in the context of applying the HoC to prevent occupational disease.

An abundance of published literature is available globally, intended to provide decision makers with a logical methodology to select controls in accordance with the control hierarchy. As stated before, control measures are defined in the Work Health and Safety Regulation as “a measure to eliminate or minimise” risk (Australian Government, 2017b, Chapter 1, Part 1.1).

On the other hand, the Work Health and Safety Act and associated regulation do not provide a definition of risk. A definition of risk however is offered in the approved Code of Practice on How to Manage Work Health and Safety Risks as, “the possibility that harm (death, injury or illness) might occur when exposed to a hazard” (Safe Work Australia 2011a, p. 4). Furthermore, a definition of risk control is also provided as, “taking action to eliminate health and safety risks so far as is reasonably practicable, and if that is not possible, minimising the risks so far as is reasonably practicable.” (Safe Work Australia 2011a, p. 4)

4.2.3 Reasonably practicable

The fundamental premise of this provision is the outcome of decisions made by duty holders are considered “reasonably practicable” in a given and specific circumstance.

Determining what is reasonably practicable has been cited as an *“objective test”* (Safe Work Australia (2013d, p. 7), however fundamentally requires duty holders to identify and provide the highest level of protection that is both possible and reasonable in a given circumstance, taking into consideration the balance of relevant matters, including:

- the likelihood of the hazard or the risk concerned occurring
- the degree of harm that might result from the hazard or the risk
- what the person concerned knows, or ought reasonably to know, about the hazard or risk, and about the ways of eliminating or minimising the risk
- the availability and suitability of ways to eliminate or minimise the risk, and
- the cost of eliminating or minimising the hazard or risk.

Costs, according to Safe Work Australia (2013d), may only be considered after assessing the feasibility and effectiveness of the measures which eliminate or minimise the risk, including whether such costs are proportionate to the level of risk reduction achieved.

Decision making with respect to the HoC is further reinforced by Manuele (2008, p. 209) who describes that decision makers, such as duty holders, should understand that level 1 and level 2 controls (detailed in Figure 1) afford greater effectiveness and are considered **preventative** controls that act to eliminate or minimise risk though design, substitution and engineering measures, all of which are less reliant on human behaviour and are less likely to be overridden by supervisors and/or workers, whereas level 3 controls are considered **contingent** controls which significantly rely on the performance of personnel in the workplace.

4.3 Life cycle of construction projects

Research supports the management of WHS across the entire life cycle of projects. For example Weinstein et al. (2005) describe a life cycle safety program implemented in a large construction project. The program extended the concept of safety in design to reflect WHS issues experienced in all phases of the facility's life cycle including, programming, detailed design, construction, operations and maintenance, retrofit, and decommissioning. Thus, the process aimed to improve WHS for all stakeholders including construction workers, equipment installers, maintenance workers, and operators of the facility.

However, within the life of a construction project, decisions taken at each stage can significantly impact workers' health and safety. Thus there is increased interest in examining ways in which WHS considerations can be integrated into decision-making at all stages in the construction project life cycle to ensure that the best possible risk control outcomes are realised. For example Cameron et al. (2008) investigated the integration of health and safety with construction project planning. Eight integrated tools were developed and found to make a difference. These were: a project responsibility chart; an option evaluation chart; health and safety hazard workshops; the inclusion of WHS information on drawings; red–amber–green lists; the inclusion of WHS milestones on programs; and a design change control process.

More recently, digital design tools and building information modelling (BIM) have been used to facilitate the integration of WHS into project planning across all stages of the construction project life cycle (Zhang et al. 2013). Tools have been developed to use digital design models to analyse work flows, automatically detect WHS hazards and suggest activity-specific preventive measures (Zhang et al. 2013). These tools have also been combined with visualisation approaches to provide workers with visual training relating to particular hazards inherent in work activities (Shen and Marks, 2015).

The focus on integrating WHS considerations can also be driven by construction clients, as is illustrated in a document developed by RMIT University on behalf of the Office of the Federal Safety Commissioner (DEEW, 2008).

The Model Client Framework utilises a generic project life cycle model, comprising 4 main stages and specifies model client management actions for each stage.

The four stages are as follows:

- (i) planning (Stage A)
- (ii) design and procurement (Stage B)
- (iii) construction (Stage C), and
- (iv) completion (Stage D).

The design stage is separated into two sub-stages covering conceptual design, and production design and procurement. Depending on the project delivery method there may be varying degrees of overlap and/or continuity of team members across stages.

The four project stages were divided into distinct phases, reflecting the main activities included in each. The Model Client documents identify client WHS management activities that can be implemented in each project stage and phase (Figure 2).

The stages and phases are described below:

The planning stage (Stage A)

The planning stage of a construction project identifies and articulates the client's need for a particular construction project. The requirements of the construction project are articulated in order to examine the variety of options that could address the identified need. During the planning stage, the alternative options for the project are narrowed until a best solution is agreed. The project brief is usually produced in this stage and preliminary approvals are sought.

The planning stage is further divided into four phases. These are:

Phase 0—Demonstrating the need (for the construction project)
Phase 1—Conception of the need (for the construction project)
Phase 2—Outline feasibility
Phase 3—Substantive feasibility and outline approval.

The design and procurement stage (Stage B)
During the design and procurement stage of a construction project, the client selects a designer (or design team). The design of the permanent facility to be constructed is developed from the selection of design solutions. Design develops from an outline to a full conceptual design. Design documentation is prepared and the costs of constructing the designed facility are reviewed. Tender documents and contracts are developed for the construction stage. Recognising the impact on WHS that design decisions can have, the WHS implications of a design should be subject to a staged review. The greatest opportunity for WHS risk reduction often occurs at the conceptual design stage. As the design progresses and design decision-making becomes more fine-grained and detailed, there are still opportunities for WHS risk reduction. The WHS risk management should be built into the design process and designs should be subject to staged review. WHS risks that are identified but cannot be resolved through judicious design should be recorded, especially where these are not risks a contractor would usually consider in their usual assessment of site WHS risks. The particular WHS issues associated with the design can then be reflected in the requirements of contract documents for the construction stage and aid the selection of a suitable and safety-competent contractor for the project.

The planning stage is further divided into three phases. These are:
Phase 4—Outline conceptual design (for the construction project)
Phase 5—Full conceptual design (for the construction project)
Phase 6—Production design and procurement.

The construction stage (Stage C)
The construction stage commences after the finalisation of the design and in a traditional model leads to the appointment of a contractor to undertake the construction of the facility. It encompasses all works on the site including any specialist tasks which may be carried out by subcontractors or equipment suppliers. The contractor is usually responsible for undertaking all of the works including provision of all materials, labour, plant and equipment required to complete the works. The contractor also controls the sequence and coordination of works to ensure that construction is undertaken in an ordered and logical way. The contractor is also responsible for coordination with the works of other parties which may be involved in the project, such as service authorities relocating their assets or contractors on adjacent projects.

Construction covers all the works required to deliver the final project, including new civil engineering infrastructure, alterations to existing facilities and installation of services and fittings. Construction covers not only the building of the facility itself but also associated activities such as delivery and removal of goods to and from the site; site access; excavations; temporary works such as false-work, formwork and working platforms; clearing and grubbing; temporary and permanent fencing; landscaping and ancillary works. Of vital importance to WHS is the proper use of construction plant and equipment in accordance with statutory obligations and manufacturers' recommendations. During the construction stage, a model client will have the benefit of planning, design and procurement decisions that have taken WHS into account — as described in booklets two and three — where opportunities to reduce WHS risks have occurred during project planning, conceptual and detailed design, and procurement. All reasonably foreseeable WHS risks will have been identified in pre-construction activities and, where these cannot be resolved, residual WHS risk information should be passed on to the contractor in the form of a project risk register. This is important for WHS risks which a contractor would not usually consider in the assessment of normal site WHS risks.

The construction stage is further divided into two phases. These are:
Phase 7—Production information
Phase 8—Construction.

The completion stage (Stage D)
The completion stage is achieved after the finalisation of construction when the facility is handed over to the client. It is the stage reached when, depending on the type of facility, plant and equipment is commissioned, occupancy is arranged and the facility is put into service for its intended use. It is usually the stage when the contractor has completed all contractual obligations and the client has issued certification acknowledging completion of the works.

Sometimes, the contractor may still have an obligation to maintain the facility for a fixed period of time after practical completion under defects liability requirements. Sometimes a project may be completed in stages, whereby handover of the facility is undertaken in discrete stages. For example, a road project may be undertaken in stages so that some sections are opened to traffic while others are still under construction. The safe operation of the facility will have been considered in all the earlier stages of the project: the planning stage, the design and procurement stage and the construction stage. These considerations include maintenance, servicing, cleaning, and facilities management. Typical WHS issues include access for internal and external maintenance and cleaning, the type of floor surfaces, elimination of manual handling, storage areas, fire evacuation, disabled access and security systems.

The completion stage does not mean the end of any further actions relating to WHS. It enables a total review to be undertaken of WHS issues during the whole lifecycle of the project—right back to the planning stage—to see if there are any lessons that can be learnt which could be fed into safety management processes for future projects.

The completion stage consists of only one phase. This is:
Phase 9—Operation and maintenance (DEEW, 2008).

4.4 Construction industry supply chain

Large engineering projects can be high-stakes games characterised by substantial irreversible commitments, skewed reward structures in the case of success, and high probabilities of failure (Miller & Lessard, 2001). These projects affect and are affected by multiple stakeholders with differing interests and demands. A project can often create a dynamic context for stakeholder management and stakeholder behaviour because the project moves through different phases during its life cycle (Aaltonen & Kujala, 2010).

Having noted this, a supply chain is a complex network with an overwhelming number of interactions and inter-dependencies among different entities, processes and resources. The network is highly nonlinear and shows complex multi-scale behaviour (Surana et al., 2005). In managing the supply chain, the couplings can be both tight and loose. They are loose in terms of the coupling between the production of building materials and what is done on site, and tight in the relationship between the activities undertaken on site and the activities carried out in the supply chain. Thus, the pattern of couplings in construction work is characterised by tight couplings in individual projects and loose couplings in the permanent network (Dubois & Gadde, 2000). As such, successful integration of the activities of the entire supply chain depends heavily on the availability of accurate and timely information that can be shared by all participants. Information technology, with its capability of setting up dynamic information exchange networks, has been a key enabling factor in shaping the supply chain to meet such requirements. However, a major obstacle remains in the deployment of coordination and decision technologies to achieve complex, adaptive, and flexible collective behaviour across complex supply chains. This is due to the lack of understanding of organisational, functional and evolutionary aspects in supply chains.

Surana et al. (2005) found that to tackle this problem supply chain networks must be treated as a ‘complex adaptive system’, not just a ‘system’. Lingard et al. (2012) also confirmed these results and found that the simplistic attribution of responsibility to a single socio-technical actor within a construction supply chain, does not reflect the multiple and disparate influences that impact upon WHS outcomes in construction projects. Lingard et al. (2012) applied actor-network theory (ANT) to better understand and analyse the interactions between human actors and non-human artefacts affecting WHS in the construction industry. ANT lends itself to the analysis of decision-making and practices in construction projects in which project teams comprise heterogeneous, self-organising coalitions of autonomous agents between whom associations vary over time (Fernandez-Solis, 2008).

Furthermore, Vrijhoef and Koskela (2000) recommend an integrated management of the interface between site activities and supply chain. Dubois and Gadde (2000) also state that relational exchanges and inter-organisational adaptations can greatly help to manage the complexities in supply chain management in the construction industry. They suggested a more integrated supply chain using collaborative agreements between contractors, suppliers and clients.

Cox and Thompson (1997) argue that competitive tendering inevitably sets the conditions for and shapes the relationships between parties that are contractually connected in the supply chain. These relationships are often typified by market-based, short-term interactions between independent businesses. Intense pressures to cut costs to remain competitive can reduce the attention paid to WHS, particularly in smaller sub-contractor organisations (Plambeck, 2012). Wilhelm et al. (2016) recently applied agency and institutional theories to explore the conditions under which first-tier suppliers can act as agents to fulfil health and safety requirements (what they call a "double agency role"). The findings, from three in-depth case studies embedded in different institutional contexts, highlight the importance of first-tier suppliers' engagement with managing the WHS standards in the supply chain.

4.5 Construction industry decision makers

A wide variety of stakeholders are involved in delivering construction projects. Safe Work Australia (2013c) specifies persons which are involved in the construction works as being:

- designers
- persons that commission construction work, including
  - builders
  - property developers
  - clients
  - owners-builders, and
  - subcontractors
- principal contractors
- persons who have management or control of a construction workplace
- persons carrying out high-risk construction work
- workers
- officers, and
- other persons, such as inspectors and visitors.

The above all have statutory responsibilities for WHS. However, Lingard et al. (2011) describe construction projects as complex socio-technical systems and explain how stakeholders who may not have statutory responsibilities or who may not be contractually involved in the delivery of construction projects can also exert a substantial influence on decisions that can impact construction workers' WHS.

In relation to occupational health and hygiene WHS advisors and hygienists are likely to play a very important role in influencing decision-making.

Further information about different stakeholders and how they can influence the selection and implementation of control measures for health risks is described in part 5.3.

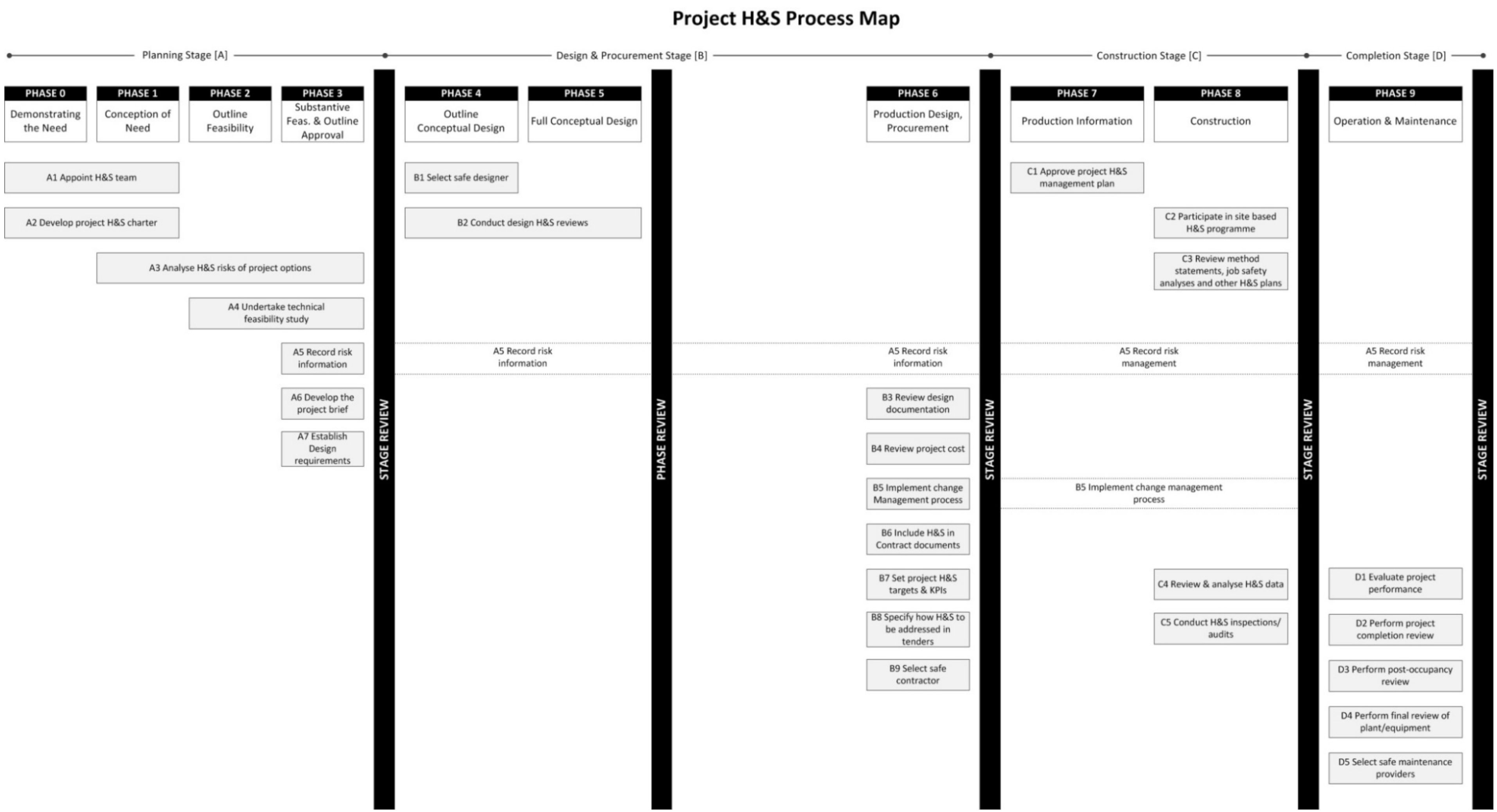

Figure 2: Model Client process map

Source: DEEW, 2008, S.13.

Part 5: Decision making

Individual / psychological factors

A feature of contemporary WHS legislation in many countries, including Australia, is the inclusion of process or management requirements (Frick and Wren, 2000). Gunningham and Sinclair (2009a; 2009b) suggest that management-based regulation is a form of meta-regulation or meta-risk management in which, rather than regulating directly, Governments seek to “risk-manage the risk” of enterprises or activities (p. 4-5).

Consistent with this framing of the legislation, a risk management approach is used within organisations to inform decision-making processes relating to the way that WHS hazards are controlled (Tchiehe & Gauthier, 2017). Assessing the level of severity of a risk allows a determination of its acceptability or tolerability. Where a risk is unacceptable, more work needs to be done to control or reduce it. Risk assessment can also inform comparisons of alternative options for controlling a particular risk.

However, the effectiveness of risk control decision-making can fail at several points in the management process, for example when preparing for a risk assessment, the selection of people to include can significantly impact the effectiveness of the assessment. In construction, for example, the inclusion of people with knowledge of construction processes and practices has been found to improve the quality of design-stage risk assessments (Lingard et al., 2018).

Gadd et al. (2004) suggest that risk assessment involves an estimation of the magnitude of the risk (i.e. how big is it?) and an evaluation of the significance of the risk (i.e. is it acceptable?). They identify numerous pitfalls observed in undertaking WHS risk assessments, which have consequences for the quality of decision-making and the effectiveness with which risks are ultimately controlled. These include:

- carrying out a risk assessment to attempt to justify a decision that has already been made
- using a generic assessment when a site-specific assessment is needed
- carrying out a detailed quantified risk assessment without first considering whether any relevant good practice was applicable, or when relevant good practice exists
- carrying out a risk assessment using inappropriate good practice
- making decisions on the basis of individual risk estimates when societal risk is the appropriate measure
- only considering the risk from one activity
- dividing the time spent on the hazardous activity between several individuals—the ‘salami slicing’ approach to risk estimation
- not involving a team of people in the assessment or not including employees with practical knowledge of the process/activity being assessed
- ineffective use of consultants
- failure to identify all hazards associated with a particular activity
- failure to fully consider all possible outcomes
- inappropriate use of data

- inappropriate definition of a representative sample of events
- inappropriate use of risk criteria
- no consideration of the 'So Far As Is Reasonably Practicable' (SFAIRP) or further measures that could be taken
- inappropriate use of cost benefit analysis
- using 'Reverse SFAIRP' arguments (i.e. using cost benefit analysis to attempt to argue that it is acceptable to reduce existing safety standards)
- not linking hazards with risk controls, and
- not doing anything with the results of the assessment (Gadd et al. 2004).

As an example, Gadd et al. (2004) cite examples in which quantitative risk assessments were used to justify decisions that had already been taken not to implement certain forms of technological risk control measures, even when these control measures were requested by a regulatory body. The argument not to implement these measures was based upon an argument that there was gross disproportion between the benefits to be achieved, in terms of risk reduction, and the costs of implementing the technological risk control measures.

Gadd et al. (2004) also cite examples of poor decision-making in which cost benefit analysis associated with the implementation of a particular technological risk control measure was based on a 'gold-plating' of the measure, i.e., the cost estimate of implementation was based on the most expensive technology available without considering alternative cheaper technologies that would apply the same risk control solution. In the case study described by Gadd et al. (2004) the costs of the (most expensive) technology was perceived as not being justified because the costs were disproportionate to the potential benefits. Therefore, when a cost benefit analysis is carried out, it is important to provide valid cost estimates instead of providing only the most expensive ones (Gadd et al., 2004).

Hopkins (2011) warns of the dangers of allowing decision-makers with responsibility for planning and designing work processes and systems to base their decisions on their own risk assessments because: "*these assessments are likely to be biased in the direction of allowing decision-makers to do what they are already predisposed to do…In particular, there are constant pressures on these decision-makers to minimize cost and hence to under-state the risks of the lowest cost [work process design] option*" (p. 115).

This literature review explores barriers to the adoption of high level technological risk controls for occupational health risks in the construction context. Issues including the failure to properly apply the principle of reducing risk to 'the So Far As Is Reasonably Practicable' (SFAIRP) are considered. Barriers relating to a lack of awareness of occupational health risks, a prevailing bias in risk perception related to health and the hyper-masculine culture of the construction industry are also explored. Finally, structural characteristics of the construction industry that militate against effective decision-making and selection of technological risk control measures for occupational health risks are examined.

Decision-making

Risk control decision-making is shaped by the criteria that are applied in terms of defining acceptability and tolerability of a particular risk. Tchiehe & Gauthier (2017) argue that the terms acceptability and tolerability are used ambiguously (and sometimes interchangeably) in relation to risk. However, the UK Health Safety Executive (HSE) distinguishes between the two concepts, as follows: "*'tolerable' does not mean 'acceptable'. It refers instead to a willingness by society as a whole to live with a risk so as to secure certain benefits in the confidence that the risk is one that is worth taking and that it is being properly controlled*" (HSE, 2001, p.3).

Tcheihe & Gauthier (2017) follow this line of thinking, defining an 'acceptable' risk as one that is worth taking because of the expected benefits, and for which the efforts invested in finding new ways to reduce it are marginal or non-existent. In contrast, a 'tolerable risk' is one that is worth taking based on expected benefits, but that remains under surveillance, and for which means of reduction continue to be sought. Thus, just because a risk is considered to be tolerable, it does not mean that new and more effective ways of reducing the risk further do not need to be sought. Concerns are also raised about the usefulness of risk assessment as a tool to guide to decision-making about methods of risk control in a particular situation.

For example, Hopkins (2011) argues that the only circumstance in which risk management practices can provide clear guidance to decision-makers is when a thorough quantitative risk assessment is used to determine a numerical risk value that can then be compared with a predetermined threshold of acceptability. In terms of WHS decision-making, this level of objective, quantified risk data is not usually available and so Hopkins argues that "*the risk continuum must be converted into a dichotomy for the purposes of decision-making*" (p. 111). Hopkins (2011) argues that, rather than base decision-making on subjective assessments of WHS risk, organisations should establish rules to guide decision-making in relation to investment in particular forms of risk control. He identifies specific examples from the petrochemical industry in which technical rules about specific forms of risk control could have averted major incidents. The role for risk management, in Hopkins' view, is to inform the establishment of these general technical rules, rather than enabling decision-makers to make decisions about particular forms of risk control on a case-by-case basis.

When applied to occupational health, a failure to apply the SFAIRP principle properly in decision-making is likely to perpetuate the selection and implementation of behavioural controls for occupational health risks, such as worker training and the use of personal protective equipment. These are often limited in their effectiveness because:

- they protect workers engaged in a particular activity but may not protect those working in the surrounding environment, or
- they are inconsistently applied by workers who may be engaged to work at a site for a limited period of time (Sherratt, 2015).

In considering barriers to the implementation of technological forms of control for occupational health risk, the awareness and application of the SFAIRP principle by decision-makers needs to be better understood. The application of technical rules relating to decision-making and the need to invest in particular forms of risk control, for example, engineering solutions, is one potential area for improvement (Hopkins 2011).

5.1 Awareness and risk perception

The ability to identify and recognise hazards is important for the effective management of work-related health and safety hazards and risks (Perlman et al., 2014). The links between risk perception and behaviour can also explain gaps between risk controls selected and documented and the way that work is actually performed.

Workers' perceptions of risk have been identified as a factor in their decision to comply with workplace WHS rules, such as the requirement to use personal protective equipment. For example, Arezes and Miguel (2008) investigated 516 Portuguese construction workers' reported use of hearing protection devices. The workers, all of whom were exposed to daily noise levels that exceeded legislated daily exposure levels, were 52% more likely to use HPDs if they perceived the risk of noise-induced hearing loss to be high. However, 45% of the workers indicated that they had never used HPDs. Arezes and Miguel (2005) also report that, although risk perception is an important determinant of workers' willingness to use HPDs, the workers were generally poor at judging risk levels in their work environment, posing a threat to effective control of risk using HPDs.

Awareness of WHS risks and appropriate methods for their control is also an important factor shaping the decision-making and behaviour of managers and professionals, who have input into decisions about the materials and methods of construction, as well as the selection of risk control measures.

Previous research shows that risks and possibilities to control them are perceived differently by construction employers and workers. Results of a study conducted in the Victorian construction industry indicate that employers' perceptions of health and safety risks are shaped by the economic environment, including prevailing industry practices. Employers' understanding of risk led them to shift responsibility for health and safety to workers and regard workers who suffered an occupational injury or ill-health as deviant or careless (Holmes & Gifford (1997). By comparison, workers accepted WHS risks as being 'part of the job' and expected that they would experience work-related injury or illness some point in their working lives (Holmes & Gifford, 1997).

Previous research also reveals that participants in different industry stakeholder groups perceive WHS risks differently (Lingard et al. 2015b). In particular, design professionals, whose decisions can impact upon WHS risk and means by which risks are controlled are familiar with acute effect injury risks, such as falling from height, or structure collapses, but are far less adept at identifying less visible health hazards, for example ergonomic issues related to musculoskeletal disorders. Recent research has highlighted the potential benefits of visualisation and the use of infographics to assist design decision-makers to better understand less visible occupational health-related risks arising from their decision-making (Lingard et al. 2018).

Biases in risk judgments are also understood to be related to psychological factors that impact decision-making and behaviour. Further, some of the psychological attributes that shape risk perceptions over-emphasise acute effect injury risks, while under-emphasising delayed effect health risks (Holmes et al., 1999).

In a study by Slovic et al. (1982) people were asked to judge the riskiness of certain hazardous activities and to indicate their desire that these be regulated or controlled. The results showed that laypersons' judgments about risk differed from those of technical experts. This is not to suggest that the risk judgements of people without technical expertise are not valid and to be overlooked. Indeed, on WHS, persons exposed to risks have a legal right to be consulted in relation to the assessment and management of WHS risks.

Also, Slovic et al. (1982) found that two dimensions were used when thinking about the riskiness of activities. These are:

i. the extent to which a risk is observable, known to those who are exposed and to have an immediate effect or to be unobservable, unknown and to have a delayed effect, and

ii. the extent to which the risk is perceived to be uncontrollable, dreaded and likely to affect those exposed, or to be controllable, not dreaded and unlikely to affect those exposed.

Generally, risks that are perceived to be high on the dread factor are considered to be more serious and in need of more urgent intervention or control than risks that score low on the dread factor. Unlike work safety risks, work health risks:

- are not always directly visible
- may have a delayed (possibly uncertain) effect, and
- may be less well understood.

These factors may explain why decision-makers do not always pay the same attention to identifying and controlling occupational health risks as occupational safety risks.

This was borne out in a study of risk control decision-making in small business construction firms in which risk controls for falls from height (and acute effect safety risk) and occupational skin disease (a delayed effect health risk) were compared (Holmes et al., 1999). In this study, workers frequently associated WHS risks with an immediate effect and were much less are of delayed effect WHS issues. The risk of occupational skin disease was believed to low and was seen too dependent on individual susceptibility and also uncontrollable (through the use of personal protective equipment). In contrast, workers believed the likelihood of falling from height to be greater, and saw this risk as controllable through the provision of appropriate access equipment. The under-estimation of the frequency of, combined with a fatalistic resignation to occupational health risks is likely to shape decisions made in relation to risk control behaviours.

Low levels of awareness and psychological biases in risk perception are therefore likely to act as impediments to the adoption of technological controls for occupational health hazards.

Further, different stakeholders have different understandings of health and safety risk and appropriate risk controls. Thekdi and Lambert (2013) similarly reveal a lack of consensus about ways to mitigate risks between stakeholders contributing to infrastructure projects. These are attributed to differences in experience, interests and perspectives brought to decision-making.

A lack of consensus between stakeholders relating to how best to control WHS risks can also be attributed to differences in risk perception. Risk perception is significantly related to risk-related behaviour and decision-making, and thereby provides an important insight into the way that specific WHS risks are understood and ultimately (Rundmo, 1996) (see previous discussion of risk perception as a barrier to the implementation of effective occupational health risk controls).

Behaviour change theories

Theories relating to changing behaviour may provide insight into barriers to the adoption of technological controls for occupational health risks. While these theories are often applied to understand the behaviour of workers, they are equally applicable to the behaviour of decision-makers who determine how work health risks will be controlled.

Van der Molen et al. (2005) identify seven levels of behaviour change that could potentially apply to key decision-makers, as follows:

(i) being aware of the risk control measure (accessible)
(ii) understanding the risk control measure
(iii) wanting to implement the risk control measure (conscious)
(iv) intending to implement the risk control measure
(v) being able to implement the risk control measure
(vi) using the risk control measure (experience), and
(vii) continuing to use the risk control measure.

Barriers can arise at any of these seven levels to prevent the implementation of technological risk control measures. Thus, theories of behaviour change (as applied to decision-makers) can provide a useful framework for understanding the source of barriers to the selection and implementation of technological risk control measures, i.e. whether these arise from a lack of knowledge/awareness or understanding, a lack of willingness or motivation to implement the measures, a lack of intention or ability to specify technological control measures, or challenges relating to the long term use and maintenance of the specified risk control measures.

Different interventions would be required to overcome barriers to the implementation if technological risk controls for occupational health hazards depending upon the nature and source of the barrier to implementation.

Plotting an organisation's maturity in relation to understanding and responding to occupational health risks can be a useful way to understand organisational response to the management of occupational health risks, and achieve progressive improvements through the supply chain in major construction projects (see Case study 1 below).

Case study 1: Measuring and benchmarking occupational health management maturity

Measuring and benchmarking occupational health management maturity

Recent attention has turned to understanding behavioural and organisational culture-related drivers (e.g. knowledge, attitudes, risk perceptions, social norms and actual risk-taking behaviour) that affect the way that occupational health is managed in the construction industry (Hopkinson et al. 2015). Hopkinson et al. (2015) describe the development of a health risk management maturity index specifically designed for the construction industry. Occupational health maturity was defined as reflecting "…not only the need to comply with minimum legal requirements. It is a reflection of the extent of proactivity that an organisation and employees have in managing the risks and their health and wellbeing at work" (p. 52).

The index is based on a maturity model that contains the following elements of maturity in occupational health management:

- Business beliefs: belief that 'health is good for work' and 'work is good for health'
- Fairness: uniformity of support provided for health and wellbeing
- Mindful: being vigilant and responsive to the full range of current and future occupational health issues
- Collective responsibility: distribution of responsibility and control of occupational health between management and workforce
- Leadership: competency and consistency in managing, leading and supervising occupational health
- Learning: learning opportunities.

The index comprises leading and lagging metrics and has been used in a large-scale survey of construction firms in the UK to position them along a five-level maturity continuum. Of particular, relevance to decision-making, the index includes a set of questions about the extent to which occupational health risks (both traditional and emerging) are factored into other types of decisions (e.g. operational, health and safety, quality, environmental, and human resource) in construction projects and business operations.

The maturity model and index were also designed to clearly address the differences between the management of occupational safety and the management of occupational health, reflecting key differences such as latency, perceptibility of risk/harm, causal attribution, foresight and responsibility for health. It was also designed to reflect a broad range of physical and psychosocial occupational health issues. Hopkinson et al. (2015) identify the need for improvements in the management of occupational health to be driven through the construction supply chain by large (tier 1) principal contractors who can influence the occupational health management activities of their sub-contractors.

Social / cultural factors

Hyper-masculine work culture

There is a growing interest in masculinity and health in an occupational context. A review by Stergiou-Kita et al. (2015) identified the following themes related to men's occupational health and safety. These are:

- the celebration of heroism, physical strength, toughness and stoicism
- the acceptance and normalisation of risk
- the acceptance and normalisation of pain, injury and illness,
- displays of self-reliance, resistance to assistance, authority and occupational health and safety practices, and
- labour market forces, productivity pressures and profit over occupational health and safety.

All of these factors have been identified as being relevant to the construction industry, which has a hegemonic, heterosexual masculine culture which "prescribes that men should engage in reckless behaviour with little regard for their own or others' well-being" (Iacuone, 2005, p. 263).

Courtenay argues that, in a masculine work culture, men are expected to present as robust, self-reliant and strong. In such cultures, taking care for one's health is considered to be an acknowledgement of vulnerability and weakness and is socially discouraged (Courtenay, 2000).

Kolmet et al. (2006) who used a socio-ethnographic approach to understand determinants of health among Australian male blue-collar workers. Kolmet et al. (2006) report that men's health expectations are low due to anticipated "wear and tear" caused by the physical demands of their work, as well as stress inherent in balancing work and family demands, and overall lifestyle. Ajslev et al. (2013) report that construction workers accept physical strain and pain as unavoidable conditions in construction work and are willing to work hard despite experiencing bodily pain to be regarded as a 'good colleague' by co-workers. Workers who complain or discuss health concerns are characterised as being petty and unfit for work in the construction environment (Ajslev et al., 2013).

Social structures and group norms in hyper-masculine work cultures have the potential to undermine the implementation of controls for occupational health risks. For example, the application of sun screen as protection against ultra-violet radiation may be discouraged as the application of skin cream suggests vulnerability and is considered to be a 'feminine' behaviour (Courtenay, 2000).

It is noteworthy that the negative impact of a hyper-masculine work culture on health-related (protective) behaviours has been observed among tunnelling workers (Lamont, 2010). In considering barriers to the implementation of technological forms of control for occupational health risk, the prevailing construction industry (as well as organisational and project-level) work cultures should be examined.

Organisational / structural factors

5.2 Industry fragmentation

The construction environment is much more complex than single organisation environments in which senior managers establish WHS policy that is translated into practice through a process of planning, resourcing, coordinating, and monitoring performance. The delivery of a construction project is characterised by complex inter-organisational relationships, information dependencies, and considerable division of labour (Dubois & Gadde, 2002).

Construction projects are delivered by several organisations across many teams and there is a growing recognition that many contributors to construction projects either make or influence decisions that have the potential to impact construction workers' WHS. In fact, in some instances, emergent WHS hazards in the construction environment can be traced back to decisions made before construction work commences (see, for example, Hecker & Gambatese, 2003).

However, developing an agreed and collective approach to managing WHS in construction projects can be difficult because project teams are temporary coalitions of people who often have different organisational and professional interests, and varying levels of knowledge and experience relating to construction processes and WHS (Toole, 2002).

Perhaps unsurprisingly, the fragmentation of the construction supply chain has been identified as a critical factor in the emergence of WHS problems in construction projects. The development of a unity of purpose with regard to construction workers' WHS can be challenging as many different contributors to the construction design and delivery process are engaged at different times under different contracts.

The allocation of risk in a construction project is normally stipulated in contracts, which have become highly diversified to respond to the variety of procurement options and situations. Unfortunately, rather than foster a genuinely collaborative approach to the improvement of WHS, many contractual arrangements deflect responsibility from one contributing party to another. Indeed, industry discussions concerning the allocation of WHS responsibility in construction projects are underpinned by a culture of 'finger-pointing' and allocating blame. This can hinder genuine attempts to embed WHS in management processes across the life cycle of construction projects.

Early project decision-making

Organisational issues and management actions are key drivers of decision-making relating to occupational health. Some decisions that are critical to the selection and implementation of high level (technological) risk controls, i.e. those that act on the work environment to reduce health risks rather than rely on workers' behaviour, are made before construction work commences. Thus, decisions taken in the project planning and design stages can impact on construction workers' health.

Unfortunately, the ability to implement technological control measures for identified WHS hazards can be reduced if risk control decisions are made once construction work has commenced. The reason for this is that the ability to influence WHS outcomes is believed to be greatest at the early stages in the life cycle of a construction project.

Once construction work has commenced, WHS risk control decisions are left to the parties engaged in the construction stage. Small modifications to the design of the construction process might be possible, but fundamental changes cannot be made at this point (Atkinson & Westall, 2010). Swuste et al. (2012) argue that leaving decisions about control measures for WHS hazards to the construction stage of a project will produce sub-optimal results because key decisions and the health and safety consequences that flow from them are already fixed. For example, administrative control measures, e.g. job rotation, or personal protective equipment, can be implemented during construction but these solutions may not address the issues of an inherently dangerous environment, e.g. one with high levels of noise, dust, vibration etc. WHS solutions identified at this stage are more likely to focus on workers' behaviour than on changing the work environment to make it safer and healthier (see, also Hopkins, 2006). This is depicted in a curve developed by Szymberski (1997) reproduced in Figure 3. Case study 2 also provides empirical evidence linking the timing of risk control decision-making to the quality of risk control outcomes.

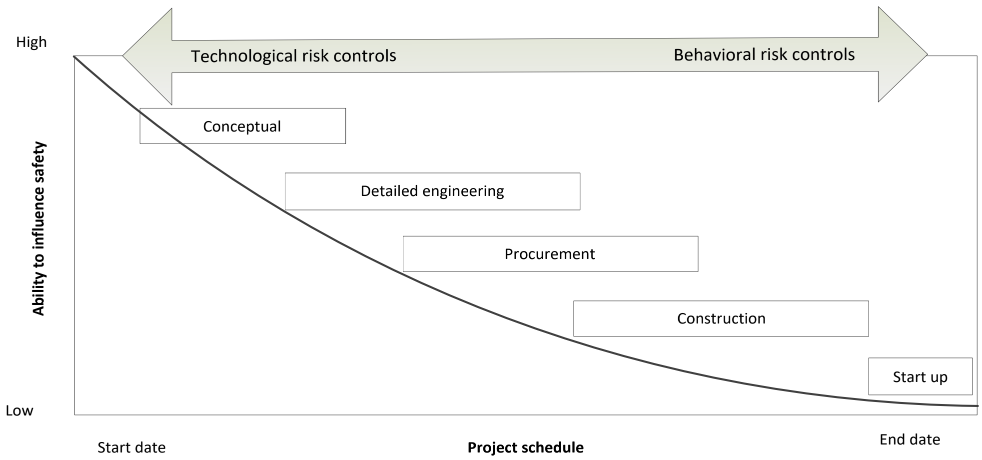

Figure 3: Time/safety influence curve

Figure adapted from Szymberski, R. (1997, pp. 69–74). (Reproduced with permission)

Taking into account the hierarchy of controls, eliminating hazards is the most effective and reliable approach to prevent occupational injuries and illnesses. However, this approach requires considering worker's health early in the design process by making design modifications so that hazards are eliminated prior to the commencement of construction (Karakhan & Gambatese, 2017; Tymvios & Gambatese, 2016). If considered early enough, some hazards can be eliminated at their source by modifying the facility design prior to construction (Karakhan & Gambatese, 2017; Karakhan 2016), or by paying attention to the implementation of technological forms of risk control (see pile-breaking Case study 2 below).

Case study 2: Timing of decision-making and effective risk control selection and implementation

Timing of decision-making and effective risk control selection and implementation

An international benchmarking study of design decision-making and its impact on construction workers' WHS tested the proposition that early consideration of risk control measures in project decision-making would produce better outcomes. The study:

- measured the effectiveness of risk controls in case study construction projects
- identified whether risk control measures were identified and developed before the commencement of construction, and
- examined whether risk control decisions made early in the project lifecycle, i.e. before the commencement of construction, were more likely to produce effective (upper level) controls for identified risks.

Data were collected from a total of 23 construction projects, 10 of which were in Australia/New Zealand and 13 were in the United States of America. The research design involved replication and cross validation across two diverse and different samples (i.e., the US and Australia/New Zealand project samples). The relationship between the timing of project decisions and the effectiveness of risk controls was evaluated in the Australian and the American data independently.

In-depth interviews were conducted with stakeholders involved in the planning, design and construction features of work particular to each project. Interviews explored the timing and sequence of key decisions, and the influences that were at play as these decisions were taken in the project context. During the course of the research 288 interviews were conducted (185 in Australia and 103 in the USA).

A positive relationship was found between the identification of risk control measures in the early stages of a construction project and the quality of risk controls implemented in the construction stage of the project. Thus, when risks were identified and control decisions taken before the commencement of construction, it was more likely that risks would be controlled at source, through the implementation of technological control measures.

When decisions were left until the construction stage, it was more likely that measures implemented to control WHS risks using the lower levels of control that rely for their effectiveness on workers' behaviour, for example administrative controls or personal protective equipment

(Lingard et al. 2015a).

Communication and knowledge sharing

Notwithstanding the growing emphasis on integrating WHS considerations into project decision-making in the planning and design stages of projects, the extent to which safety and, more so, health considerations are properly integrated into pre-construction decision-making is questionable.

One challenge to the effective design for health and/or safety in the construction industry lies in the degree to which there is vertical segregation between participants engaged in the initiation, design, production, use and maintenance of facilities (Atkinson and Westall, 2010). In particular, the traditional separation between the design and construction function can impede the development of shared project goals (Baiden & Price, 2011, Karakhan & Gambatese, 2017) and can negatively impact on project outcomes (Love et al., 1998).

A recent review of WHS in the UK construction industry identified the separation and poor communication between the design and construction functions as a causal factor in construction fatalities (Donaghy, 2009). The organisational and contractual separation of the design and construction functions reduces the possibility of free-flowing communication between constructors and designers (see Atkinson &Westall, 2010). This is a problem because communication is critical to effective decision-making in relation to the best ways to control WHS risks.

There is emerging research evidence that design professionals are not sufficiently well versed in knowledge of construction methods and/or WHS to fulfil their responsibilities for safety in design (Yates & Battersby, 2003). In the UK Brace et al. (2009) report that '*many designers still think that safety is "nothing to do with me," although there are a small cohort who want to engage and are having difficulty doing this because they do not fully understand what good practice looks like'* (p. 12). Consequently, Donaghy (2009) recommended that accrediting bodies establish specific requirements to embed WHS in the education of all professionals engaged in the delivery of construction projects, particularly those with 'upstream' roles.

It is frequently stated that collaborative or integrated forms of project delivery improve buildability and, by implication, have the potential to also improve WHS (Bresnen & Marshall, 2000; Kent & Becerik- Gerber, 2010). However, Ankrah et al. (2009) comment that the procurement method cannot, of itself, create a positive cultural orientation towards WHS.

Similarly, Atkinson and Westall (2010) point out that the adoption of an integrated project delivery approach does not guarantee positive WHS risk control outcomes. Integrated project delivery mechanisms create favourable conditions for the integration of WHS into construction project planning and design activities, but actual improvements in the implementation of technological WHS risk controls are likely to occur as a direct result of the increased communication and information exchange among project participants. Of particular importance is when people who do the construction work, usually sub-contractors, can share information about the WHS impacts of design decisions, as well as practical insights into the best ways to control WHS risks.

An analysis of communication and decision-making in construction project teams utilising social network analysis demonstrated that the more central a construction contractor is in terms of communicating ideas and having input into health and safety-related decision-making during the design and planning stages of a construction project, the more likely it is that effective technological risk controls are implemented for identified WHS hazards (Lingard et al. 2014). This may be because construction contractors possess critical information about the materials, methods and technologies to be deployed in construction. This detailed knowledge of construction processes is likely to be important to the identification of WHS risk control measures that are likely to be the most effective and practically implementable in a particular project situation.

Lingard et al. (2014) consequently suggested that ensuing construction process knowledge is available to decision-makers in the design and planning stages can help to improve the quality of WHS risk controls 'designed in' and ultimately implemented in the construction stage. In many instances this detailed knowledge about construction processes may not reside with the principal contractor but with a specialty sub-contractor (Franz et al. 2013), increasing the importance of engaging subcontractors as early as possible in decision-making relating to WHS risk control. Figure 4 depicts the potential benefits of ensuring that detailed construction process knowledge is available to people engaged in pre-construction decision-making.

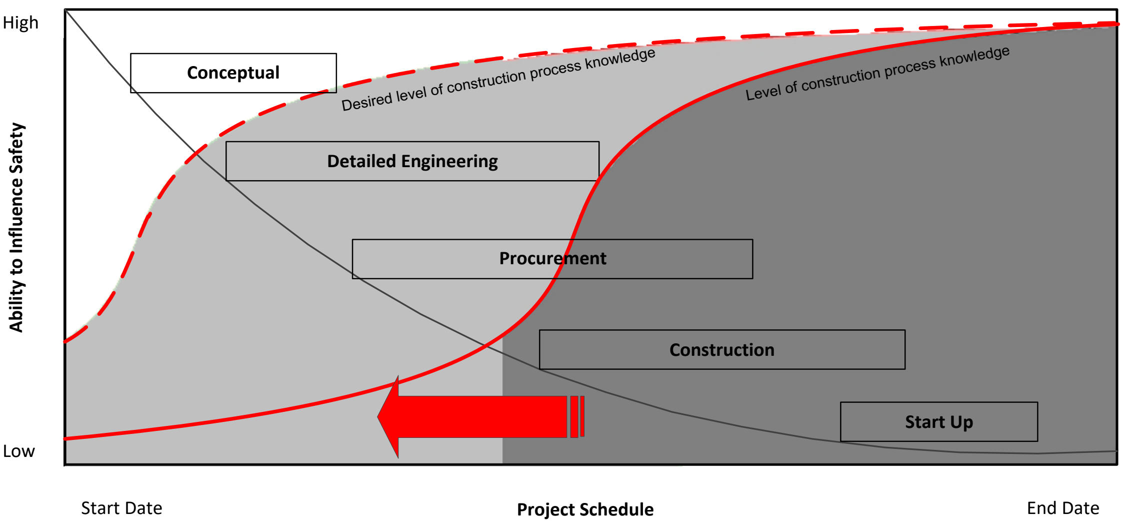

Figure 4: Time-process knowledge influence curve
Figure adapted from Szymberski, R. (1997, pp. 69–74.)

The following case study also highlights the importance of considering occupational health risks and the best ways to control them at the design stage of a project.

Case study 3: Health by design - Breaking concrete piles

Health by design - Breaking concrete piles

Breaking down the tops of concrete piles to expose steel reinforcement bars has traditionally been carried out using hand-held pneumatic breakers (see Figure 5).

Figure 5: Using a hand-held pneumatic breaker to break down concrete pile heads

This method of pile-breaking involves several health hazards, including exposure to Hand Arm Vibration (HAV), dust, noise and the risk of work-related musculoskeletal disorder (Gibb et al. 2007).

A recent study in the Australian construction industry revealed that systems of work designed to reduce the exposure to these hazards while breaking down piles were not effective. In particular, an integrative passive risk control method was intended to be adopted. This method involved the installation of a layer of non-bonding material (foam) at the cut-off point during construction of the concrete piles. This material is installed before the concrete is poured.

If performed effectively, the incorporation of the non-bonding material would significantly reduce the duration of the mechanical breaking activity. One participant reported that failure to install the material correctly increased the duration of the task from one to approximately four to five hours per pile.

The study revealed that the pile construction work and pile breaking work were undertaken by two different subcontracted work crews. In many instances, the pile construction crew did not install the non-bonding material correctly, resulting in a substantial increase in health risk exposure for the workers who would subsequently break the pile heads.

This indicates how a lack of attention to the coordination of work crews and/or management of the quality of work produced an unnecessary and unanticipated level of health risk. In this case, the risk control measure that was specified was rendered less effective due to weaknesses in the on-site management processes.

However, if considered at the design stage of a project, technological (substitution) risk controls are available.

Several commercially available hydraulic pile-breaking technologies are available, although there are some limitations relating to the dimension of piles that can be broken by these technologies and they are also unsuitable for use on diaphragm walls (EFFC, 2015).

In addition, 'integrated' active systems have been developed. These systems incorporate an active pile breaking system within the pile. This system is activated when the concrete is cured. An example of an integrated active pile-breaking method is the 'Recepieux' system, which introduces chemicals into the pile through carefully positioned ducts which deliver the chemicals to expansion chambers at the desired cut off height.

Another method under development by Laing O'Rourke uses water pressure to crack the pile at cut-off level using a system of crack inducing pipes. These are integral to the steel reinforcing cage (EFFC, 2015).

Figure 6: The Recepieux pile breaking method

Source: Recepieux (2015) reproduced with permission

The adoption of 'integrated' active systems of pile breaking require intervention at the early design and planning stages of construction work (Gibb et al. 2007).

A failure to adequately consider the health risks associated with mechanical pile-breaking using a pneumatic breaker at the design stage is likely to be a barrier to the adoption of these methods.

Furthermore, a failure to fully appreciate the potential production efficiency gains associated with these methods is also likely to act as a barrier to their specification.

5.3 Multiple stakeholder engagement

Supply networks in the construction industry are complicated and, as described above, several structural barriers to the selection of high order risk controls measures for occupational health risks are present.

Multiple stakeholders can influence the selection and implementation of control measures for health risks.

These can be classified as users, importers, decision makers, and facilitators of risk control measures (van der Molen et al., 2005). According to van der Molen et al. (2005), users, work with the proposed measures. Importers are people that facilitate the implementation of the measures in daily work, either directly or indirectly. Decision makers advise or decide about whether the implementation of the measures in the work situation will take place. Finally, facilitators act outside the companies that implement the risk control measures but still have considerable influence over their selection and implementation (e.g., regulators, unions or research organisations). During the implementation of risk controls, all stakeholders should be considered in order to identify and address barriers to the implementation of the control measures.

Construction industry stakeholders with the potential to influence the selection and implementation of WHS risk controls can also be broken down into groups that are internal or external to the project and those that either supply products or services to the project (e.g. contractors, design professionals or suppliers of plant and materials) or whose demands are to be met by the project (the client or the end user of the facility being constructed). This is represented in Figure 7.

A 'whole industry' approach to construction workers' requires the active engagement and input of all participants in the project delivery process, including:

- government and WHS regulators, owners/clients
- industry associations
- the numerous contributors to the design of a building or structure
- occupational hygienists, occupational physicians
- constructors
- specialist sub-contractors, and
- suppliers of plant, equipment, and materials.

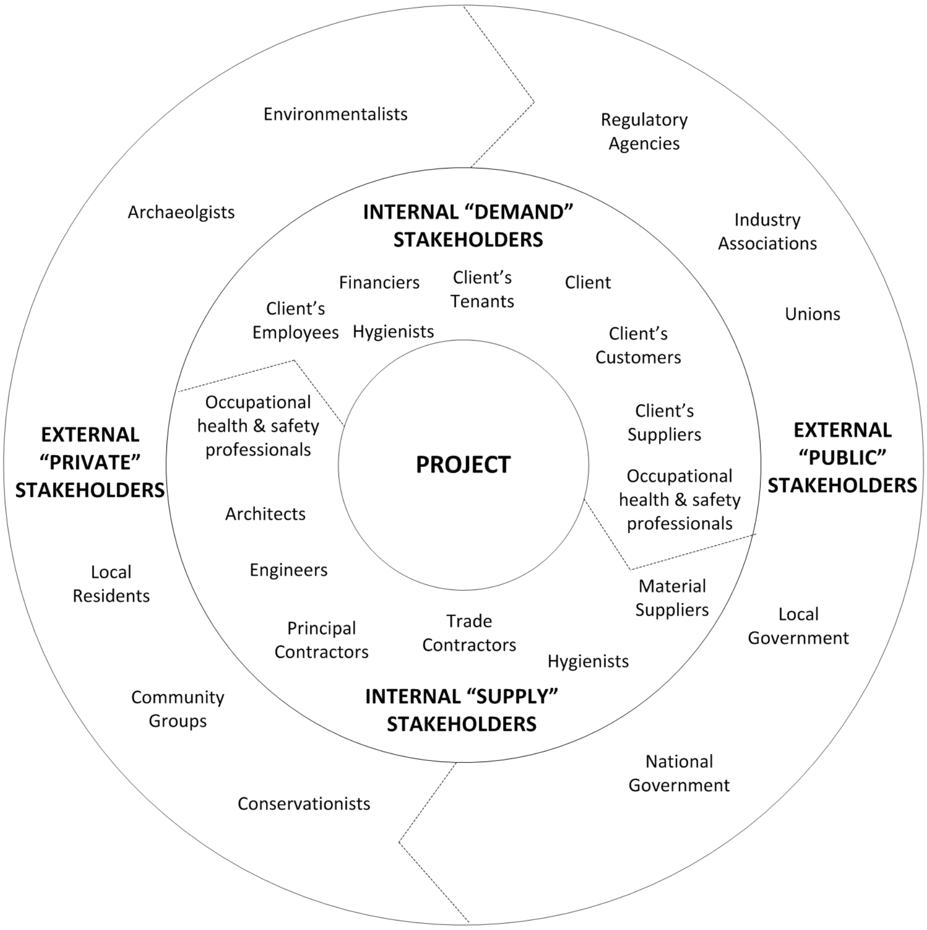

Figure 7: Stakeholders' whose activities could influence risk control decision-making

Figure adapted from Winch, G. M., (2010) (Reproduced with permission)

One challenge to the effective selection and implementation of risk controls lies in the fact that integrated approach across stakeholder groups is difficult to achieve. A survey conducted by Toole (2002) revealed that design engineers, principal contractors and sub-contractors differ in their opinions of how responsibility for workers' WHS should be shared. Similarly, in the USA, Karakhan and Gambatese (2017) state that contractors, workers, designers and other stakeholders differ in their opinions of how responsibility for construction WHS should be allocated and/or shared between contributors and professionals. Zhao et al. (2016) also analysed the WHS risk perceptions of architecture, engineering and construction professionals and found significant intra-group concordance and inter-group differences. They conclude that WHS risks contain social attributes that result in them being perceived subjectively and differently by members of distinct professional groups. Understanding this discordance in risk perception is arguably useful in accommodating a diversity of views in multi-stakeholder decision-making related to appropriate controls for WHS risks.

5.4 Commercial pressures and sub-contracting

Mayhew, Quinlan and Ferris (1997) define subcontracting as '*the process of subletting the performance of tasks*' (p.163) but suggest that this can take many forms, including self-employment, outsourcing, body hire, independent contracting and the use of agency labour. Mayhew et al (1997) suggest the boundary between these employment categories are blurred, precluding a neat and exclusive definition of subcontracting. It is also difficult to accurately measure the extent of subcontracting in Australia, either in terms of value of work or number of workers.

However, economic priorities, technological and regulatory changes and market uncertainty have all contributed to an increase in subcontracting by Australian construction organisations.

In construction, a subcontractor is '*a firm that contracts with a general contractor to perform some aspect of the general contractor's work*' (Arditi, 2005, p.866). Subcontracting has long been a feature of the construction industry in Australia (and many other countries), as the operations of general contractors are not sufficiently extensive to justify the full-time employment of skilled craftsmen in all of the requisite construction trades. Neither, in the context of market volatility, is it feasible for construction firms to own, operate and maintain specialised equipment that might have a limited use in a construction project.

Increasing technological complexity has also increased the numbers of specialist subcontractors, able to perform their specialist construction activity more efficiently than a general contractor. The contribution of specialist subcontractors is no longer limited to manufacture, supply and installation activities according to well-designed specifications. Increasingly, specialist subcontractors provide design inputs (Yik et al., 2006). Thus, subcontractors have a key role to play in making decisions that 'design out' risks to workers' health and safety. However, the extent to which subcontractors are engaged in decision-making relating to safety and, even more so, to workers' health, may be limited due to the timing of their involvement in project decision-processes.

The percentage of construction work that is undertaken by specialist and trade subcontractors is estimated to be as much as 90% of the total value of a construction project (Hinze & Tracey, 1994; Kumaraswamy & Matthews, 2000). The proportion of work subcontracted is higher in building than civil engineering projects (Arditi, 2005).

A large number of subcontractor organisations operating in the construction industry are small (even micro-businesses) because the industry is characterised by a pyramid style structure of multiple layers of sub-contracting. In the Australian construction industry 94% of businesses employ less than five people and less than one per cent employ more than 20 people (Commonwealth of Australia, reported in Karim et al., 2006). However, not all subcontractor organisations are small businesses and there are many medium and even large subcontractor organisations providing specialist or trade services. As small businesses, subcontractors may have less well developed WHS management systems and may not possess in-house specialist occupational health or hygiene specialists, limiting the extent to which occupational health risks are effectively managed.

Within the construction industry, the prevalence of subcontracting is cited as a challenge for many aspects of the industry's performance. Reasons for this include the fact that easy entry into the construction industry has enabled subcontractors to establish themselves with little capital investment and often with insufficient experience, or capability to undertake work to accepted standards (Kumaraswamy & Matthews, 2000). Further, because many subcontractor organisations are small, they are often purported to have insufficient resources to devote to the application of modern management techniques, including those related to the management of WHS (Karim et al 2006). For example, the under-capitalisation of subcontractor organisations has been identified as an impediment to the adoption of highly effective health and safety measures by Australian construction subcontractors (Loosemore & Andonakis, 2006)

Relationships between principal contractors and subcontractors are sometimes reported to be poor. Practices like post award 'bid-shopping,' in which principal contractors try to get subcontractors to decrease their submitted bids, and delayed payment for services create competitive pressures and encourage 'corner cutting' (Arditi, 2005; Hinze & Tracey 1994). The development of long-term relationships between principal contractors and subcontractors has been recommended as a means to create better working relationships. However, despite the increasing use of 'relationship' contracting and the consideration of non-cost criteria in the selection of principal, subcontractor selection and management remains cost-driven and 'arms-length' (Greenwood, 2001).

Subcontracting is often linked to poor WHS performance. For example, in one Finnish study, Salminen et al. (1993) report the risk of serious occupational accidents to be significantly higher for employees of subcontractors than for employees of principal contractors. In construction, subcontracting is acknowledged to present a challenge to the effective management of WHS. The presence of multiple subcontractors on large projects makes it difficult to coordinate WHS while, on smaller projects, subcontractors can sometimes be unsupervised (Breslin, 2004).

While larger companies in the construction industry have invested heavily in the development of formal workplace health and safety management systems (WHSMS), many subcontractors in the industry do not have the money or resources (including time) to implement an WHSMS. Further, Breslin (2004) argues that competitive pressures in the construction industry are so great that principal/head contractors frequently award work to subcontractors whose WHS practices are poor.

Once engaged, subcontractors are then placed under even greater pressure to 'cut corners' as a result of unrealistic construction programmes, with the result that a culture of completing the job as quickly as possible and moving to the next project prevails (Breslin, 2004).

Mayhew et al. (1997) compared the WHS experiences of directly employed with those of self-employed and subcontracted workers in four Australian industries, including building. They report that, within the building industry, self-employed and subcontracted workers are focused upon their precarious employment, the level of reward for effort expended, competition for contracts and getting paid for work done. These concerns result in the intensification of work and a perception that a 'level playing field' did not exist because 'cutting corners' with regard to WHS is rewarded. In the building context, subcontractors feared that the adoption of WHS practices would result in a loss of contracts and financial penalty. Risk taking and injury were accepted as ‘part of the job.’

Mayhew et al. (1997) also report self-employed and subcontracted workers in the Australian construction industry are exposed to a high incidence of verbal abuse and threats, indicating a situation in which interpersonal relationships, particularly between different subcontractors, are strained. Reasons why subcontracting is linked to poor WHS outcome are summarised below:

(1) Economic and reward factors

Pay for subcontract work is usually based on work completed, rather than time spent engaged in the work, which rewards the completion of tasks in the shortest possible time. Consequent economic priorities detract from WHS activities. Work intensification also creates higher levels of stress, fatigue and increases the risk of injury.

(2) Disorganisation effects

Subcontracting can be horizontal (multiple subcontractors), vertical (pyramid subcontracting) or both. The organisational complexity of subcontracting creates ambiguity and unclear relationships between different groups of workers. The existence of many groups of workers, who may be strangers to one another, undermines WHS control systems and increases the likelihood of errors of omission and communication failures (known causes of WHS incidents). Fragmentation involved in the employment of multiple small subcontractors also reduces the resources devoted to WHS as small to medium sized enterprises (SMEs) are known to devote less resources to WHS. In some instances, subcontracting might even be an attempt to deliberately evade legal WHS responsibility (Mayhew et al., 1997)

(3) Inadequate regulatory control

Complex multi-employer worksites and/or numerous isolated worksites create complex environments for regulatory control. Lines of responsibility can be obscure.

The resources of enforcement agencies are stretched under these conditions. Further, subcontractors and self-employed workers are less likely to be covered by union negotiated collective agreements, removing this level of scrutiny of WHS standards.

(4) Ability to organise

The fragmentation of workers into groups operating in different workplaces, often in fierce competition with one another for work, reduces the opportunity for workers to organise. Membership of employer groups or unions is lower and opportunities to seek advice or negotiate for WHS improvements are reduced.

A fundamental principle of WHS management is employer-worker consultation regarding WHS. Research consistently shows that genuine consultation and worker participation in WHS processes and decision-making yield higher levels of WHS performance Cameron et al., 2006). British research suggests that the construction industry reliance on sub-contracting undermines employer-employee consultation regarding WHS. Walter & James (2009) report that sub-contracted workers in the UK construction industry are less informed about project WHS management activities and WHS risks than workers employed by the principal contractor. Employees of subcontractor organisations are also reported to receive less training and perceive their managers as less effective at managing WHS than employees of the principal contractor.

Walter and James (2009) report that on-site employment arrangements were a serious impediment to subcontracted workers' participation in the WHS process and that, with each successive link in the sub-contracting chain, the level of worker engagement in WHS activities diminished.

These characteristics of the sub-contracting system adopted in the construction industry form structural impediments to effective consultation and the selection of controls that reduce safety risks so far as is reasonably practicable. However, it is likely that these impediments are more acutely evident in decision-making relating to the control of occupational health risks.

5.5 Framework for factors influencing decision-making

As described above the body of knowledge focuses on safety, and although it offers some insight into the factors that influence the application of the HoC, it fails to provide empirical evidence regarding the relationship between those factors that influence decision-making relevant to prioritising the control of hazards that cause occupational illness in construction workers.

The factors described above can be clustered as follows:

- Organisational/ structural factors, which include
    - Industry fragmentation
    - Early project decision-making
    - Communication and knowledge sharing
    - Multiple stakeholder engagement, and
    - Commercial pressure and sub-contracting
- Social / cultural factors, which include
    - Hyper-masculine work culture
- Individual / psychological factors, which include
    - Awareness and risk perception,
    - Biases in risk judgments, and
    - Lack of motivation / knowledge / willingness or ability

These factors can arise on different levels and prevent the implementation of high order risk controls. Moreover, these factors may interact with each other and may influence factors on another level. An overview of the relationships that may exist between these factors led to the development of a preliminary framework which is depicted in Figure 8.

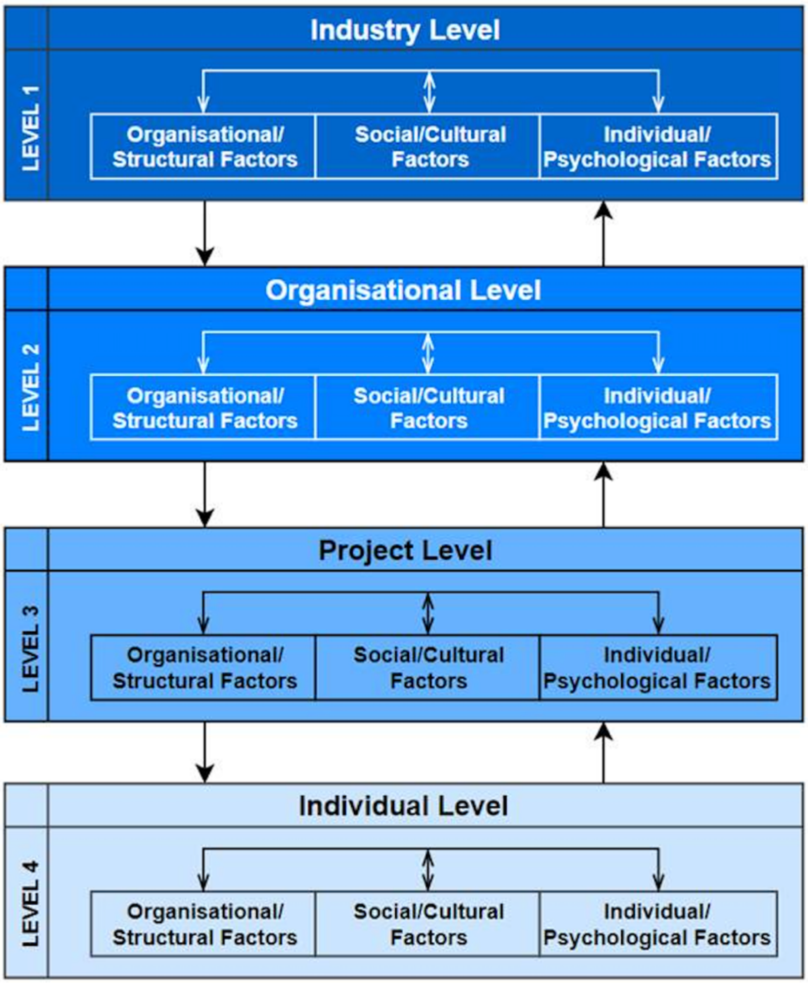

Figure 8: Preliminary conceptual framework of factors influencing decision-making

This preliminary conceptual framework offers an overview where potential barriers could be located. Future research can be designed to investigate further factors that influence decision-making, relationships between these factors and how such factors occur at different levels in the construction lifecycle that subsequently influence the application of the HoC to manage occupational health risks.

Part 6: Conclusion and next steps

A duty to reduce WHS risk so far as is reasonably practicable is a feature of WHS legislation, requiring duty holders to identify hazards, assess risks, understand the available controls for those risks and select those controls which afford the highest level of protection that is reasonably practicable.

However, the literature implies that the construction industry's management of occupational health risks may not be as well developed or effective as the management of safety risks. The bundling together of health with safety in most management activities does not acknowledge that health is a very different concept to safety, and therefore health needs its own parameters and management approaches. Further, bundled WHS management approaches (including the application of the risk control hierarchy) are currently not effectively controlling hazards that impact construction workers' health.

A significant volume of literature has been published regarding the application of the HoC for the purposes of controlling health and safety risks. However, the review of this literature reveals that the majority of content focuses on safety outcomes and fails to address health outcomes. Therefore, the body of knowledge is incomplete. This knowledge gap is reflected in an inherent focus on safety and subsequent failure to adequately focus on work-related health hazards. This is in spite of the fact that, for every one worker who dies from a work-related injury in Australia, more than eight will die from an occupational disease (Safe Work Australia, 2012). These statistics reinforce the urgency and need for research focused on the management and control of occupational health risks.

While not definitive, the literature does provide some insights into how some barriers to the selection and implementation of high order (level one and two) risk controls for occupational health risks may arise.

While safety in design is now well-established, the research shows that far less attention is paid to designing for construction workers' health. Further, the traditional separation of design and construction reduces design decision-makers' ability to access construction process knowledge. Design decision-makers are also less aware of less visible WHS risks, including exposures that can impact workers' long-term health. In addition to this, much construction work is performed by specialist subcontractors who possess an in-depth knowledge of construction technologies and work processes. Engaging these subcontractors in decisions relating to the management of occupational health risks is important in early project decision-making, yet this is challenging under some procurement and project management conditions.

Psychological biases in risk perception are also reported in the literature, whereby industry participants over-emphasise acute effect safety risks, in relation to risks that are perceived to be less certain, cannot easily be imagined or that have delayed effects.

The construction industry's hyper-masculine culture has also been identified by social researchers as a barrier to the improvement of construction workers' health.

International and Australian studies reveal construction workers are concerned about their health, but accept occupational illness as an inevitable aspect of working in the construction industry.

In the interests of reducing occupational health risk to as low as reasonably practicable, it is important that construction industry decision-makers, at all stages in the project life cycle, identify, select and implement high level risk controls. However, the literature review has revealed complex organisational, psychological and social/cultural barriers which might prevent or limit the selection and implementation of level one and two controls.

The literature review has documented risk control hierarchies for a number of significant occupational health hazards associated with construction work activities. These hierarchies show that level 1 and 2 controls are available for these significant health hazards. Important questions therefore remain about why these controls are not selected in many circumstances.

Decisions that impact workers health (and safety) are made across the project life cycle and clients can play a key role in ensuring effective management of occupational health within and between project stages and activities. The current literature does not identify all stakeholders involved in decision making and all potential barriers associated with controlling occupational health risks in accordance with the HoC. Moreover, it does not offer an explanation of the relationship between organisational/structural, individual/psychological and social/cultural factors that can impact upon the effectiveness with which occupational health risks are controlled. Thus, future research should identify all decision-makers who can influence risk control outcomes across the life cycle of construction projects, and examine all of the potential influencing factors that shape the way in which occupational health risks are managed. Research is also needed to understand the relationship between organisational/structural, individual/psychological and social/cultural factors that impact risk control decision-making across the project life cycle in order to reduce the barriers to and create conditions that enable the implementation of effective forms of risk control for occupational health risks.

This literature review forms the output of the first stage of a research project and is the foundation for the design and implementation of a primary data collection strategy to gain a fuller understanding of:

- what influences decision making in relation to the control of significant occupational health risks at all levels of project execution in the Australian construction context
- how effective current WHS management systems and practices are at prioritising high level (level one and two) controls for significant occupational health risks, and
- how best to overcome barriers to the adoption of level one and two risk controls, and to create project conditions that encourage and enable the selection and implementation of the effective controls for significant occupational health risks

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Part 8: Appendix A: Risk controls of selected occupational health hazards

In this part of the review, we summarise the control measures for major occupational health risks identified as being relevant to large scale civil infrastructure construction projects. These control measures are presented in order of the HoC as presented in Part 4.2.2.

In selecting methods to reduce the risk of occupational injuries or ill-health, decision-makers must first understand all of the available control methods that could be implemented and then start from the top of the hierarchy and work down, ensuring that they select the highest level of control measure that can be implemented.

Figure 9 provides a flowchart depicting the recommended process for the selection of controls for WHS hazards and risks.

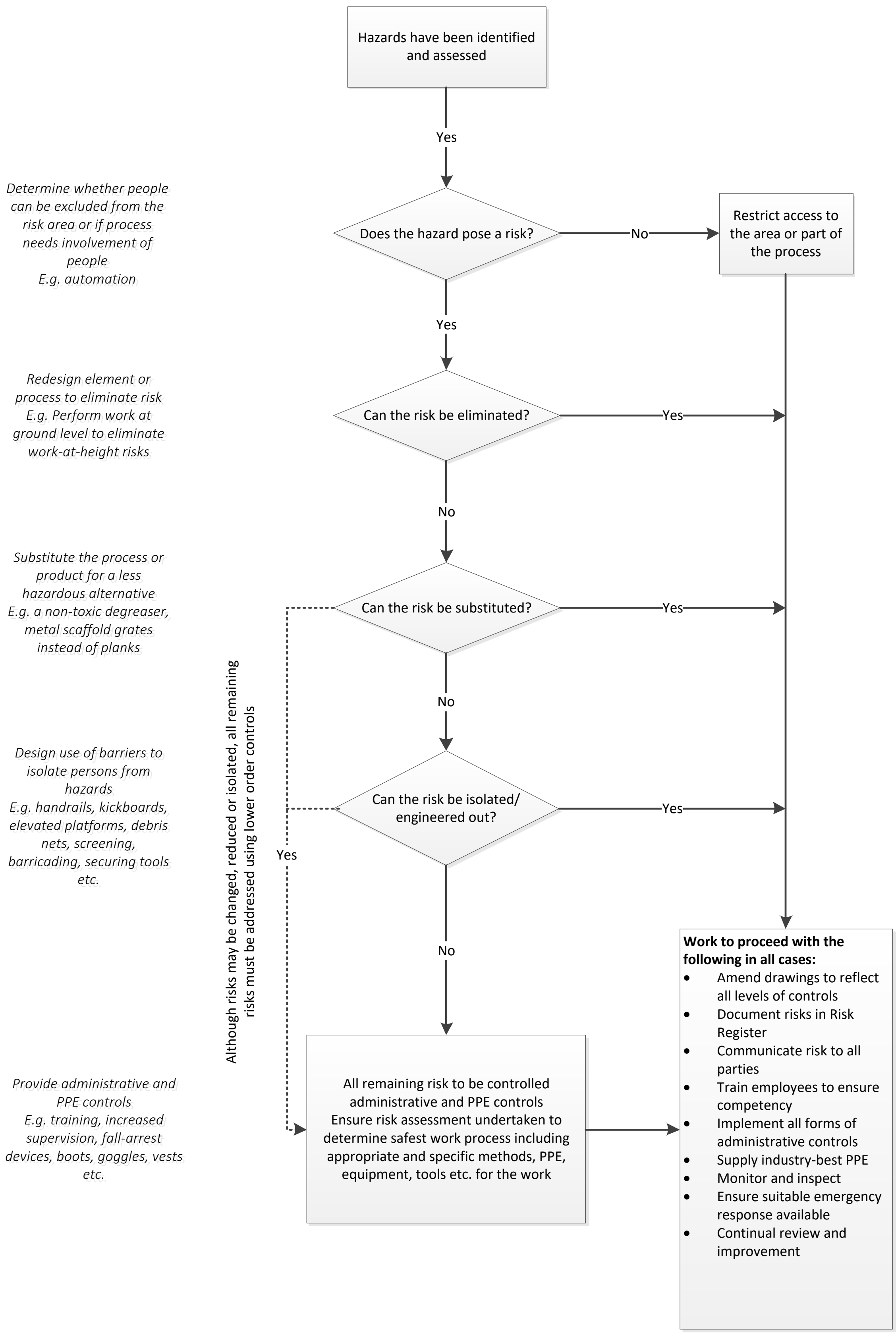

Figure 9: The recommended process for the selection of controls for WHS risks.

The following controls are also summarised in Appendix B of this review and will inform subsequent stages of the research in which decisions made risk control methods and the practical implementation of risk control strategies for occupational health risks will be explored in detail in live construction projects. This overview is structured per hazard starting with control measures for diesel engine exhaust.

8.1 Control measures for diesel engine exhaust emissions

Diesel exhaust is a mix of different gases, liquid aerosols, vapours and a variety of particulate substances (Safe Work Australia, 2015b). Diesel engine exhaust on construction sites is emitted by heavy vehicles equipped with an engine motor, such as trucks or items of mobile mechanical plant, such as excavators, bulldozers, rollers, graders and scrapers (Safe Work Australia, 2015b).

Studies support an association between lung cancer and diesel-engine exhaust (Benbrahim-Tallaa et al., 2012).

A recent study published by Peters et al. (2016) (with data collected between 2003 and 2015) analysed the long-term effects of the occupational exposure to elemental carbon, which is used as specific marker of diesel exposure, in Western Australian mines. The results of the study show that the levels of exposure to diesel exhaust in the mining industry are associated with a significant excess number of lung cancer deaths. Their study supports the need for further controls of diesel exhaust.

Workplaces and tasks in which workers are exposed to diesel engine exhaust should be identified and the level of risk assessed. A variety of control measures can be used to eliminate or to reduce the harm of diesel engine exhaust. Where possible, diesel powered plants and vehicles should be replaced with electrically driven, propane, compressed natural gas or petrol-fuelled vehicles to eliminate diesel engine exhaust (HSE, 2012a, Safe Work Australia, 2015b, OSHA, 2013).

However, where this is not feasible, substitution can be achieved by using lower diesel emission engines or more fuel-efficient engines (BAuA, 2009, HSE, 2012a). These substitution measures do not only focus on engines, but also apply to fuels. Cleaner fuels like sulphur diesel fuels can contribute reducing diesel engine exhaust (HSE, 2012a).

A range of engineering controls can also be applied to diesel engine exhaust emissions if an elimination or substitution solution cannot be implemented. The most effective engineering controls are:

- installation of engine exhaust filters
- installation of a local tailpipe exhaust ventilation, and
- installation of dilution ventilation (Karpinski, 2015).

Engine exhaust filters remove diesel particulates directly from the exhaust stream and are installed at the pipe or in the exhaust system (Karpinski, 2015). Different types of engine exhaust filters are available. Kapinski (2015) proposes a filter system which is able to reduce diesel particulate by 90 per cent. This system consists of a porous ceramic filter, a diverter valve which is installed in the exhaust pipe plus an electronic control module. Even though it is highly effective, this control measure has some limitations, including its weight, which is between 9 and 14 kilograms, and its need for servicing every 30 operating hours (Karpinski, 2015).

Even more effective are two-stage diesel emission control systems. Those capture the exhaust at the tailpipe of plant/machinery and are supported by radio signals which activate a filtration system when a vehicle enters a pre-defined workzone. Other exhaust filters, such as filter traps, can reduce diesel particulates and reduce emissions by at least 80 per cent. However, these may be less effective than the ceramic filter system and the two-stage diesel emission system (Karpinski, 2015).

Another possibility is the implementation of local tailpipe exhaust ventilation which attaches a hose to the tailpipe and connects the tailpipe to a fan as presented in Figure 10 (Karpinski, 2015, HSE, 2012a, OSHA, 2013). The diesel exhaust and gaseous emissions are sucked through the pipe and disposed of outside of the worksite, thereby not contaminating the work area (Safe Work Australia, 2015b).

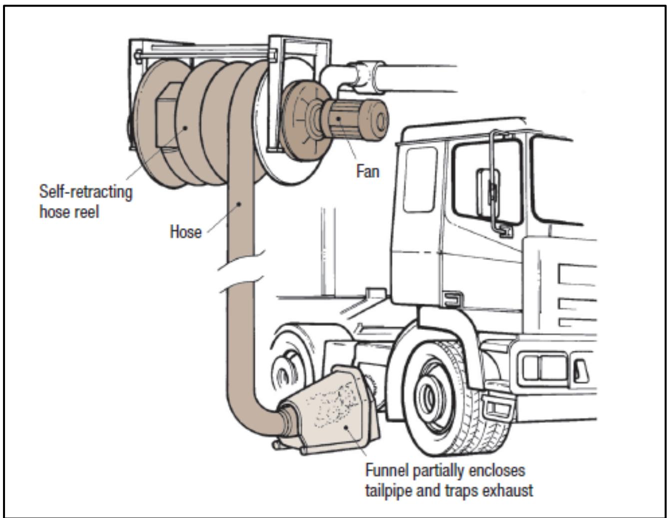

Figure 10: Fixed hose with a funnel-hype local exhaust system

Source: HSE (2012a, p. 9).

Exhaust hoses can be installed with an automatic disconnect feature or be connected to an overhead rail to keep the hose away from the ground (Karpinski, 2015). Several types of exhaust hoses are available. However, local tailpipe exhaust hoses are only effective when they are attached and used by workers. Although they physically remove a hazardous emission from the workplace, these controls still rely on human behaviour for their effectiveness (Karpinski, 2015).

Other local exhaust ventilations can also be considered. Those solutions include exhaust gas recirculation, catalytic converters or selective non-catalytic reduction (HSE, 2012a, Karpinski, 2015). Exhaust gas recirculation involves the recirculation of the nitrous oxide produced by the engine back into the engine cylinders, replacing excess oxygen in the pre-combustion mixture reducing combustion heat and the generation of pollutants (Karpinski, 2015).

Workplace ventilation techniques include dilution ventilation systems (Karpinski, 2015) or local extraction ventilation systems (HSE, 2012a). Dilution ventilation systems use wall or roof fans to push emissions towards vents while fresh air flows inside a structure through supply openings or open doors (Karpinski, 2015). Extraction ventilation systems use mechanical extraction fans to remove emissions. Air fans can also be installed to deliver fresh air to a work area (Karpinski, 2015). Where used, it is recommended that the dilution ventilation rate should be 100cfm per horsepower based on the average operating conditions set by the American Conference of Governmental Industrial Hygienists (Karpinski, 2015).

Examples of natural and mechanical dilatation ventilations are presented in Figure 11.

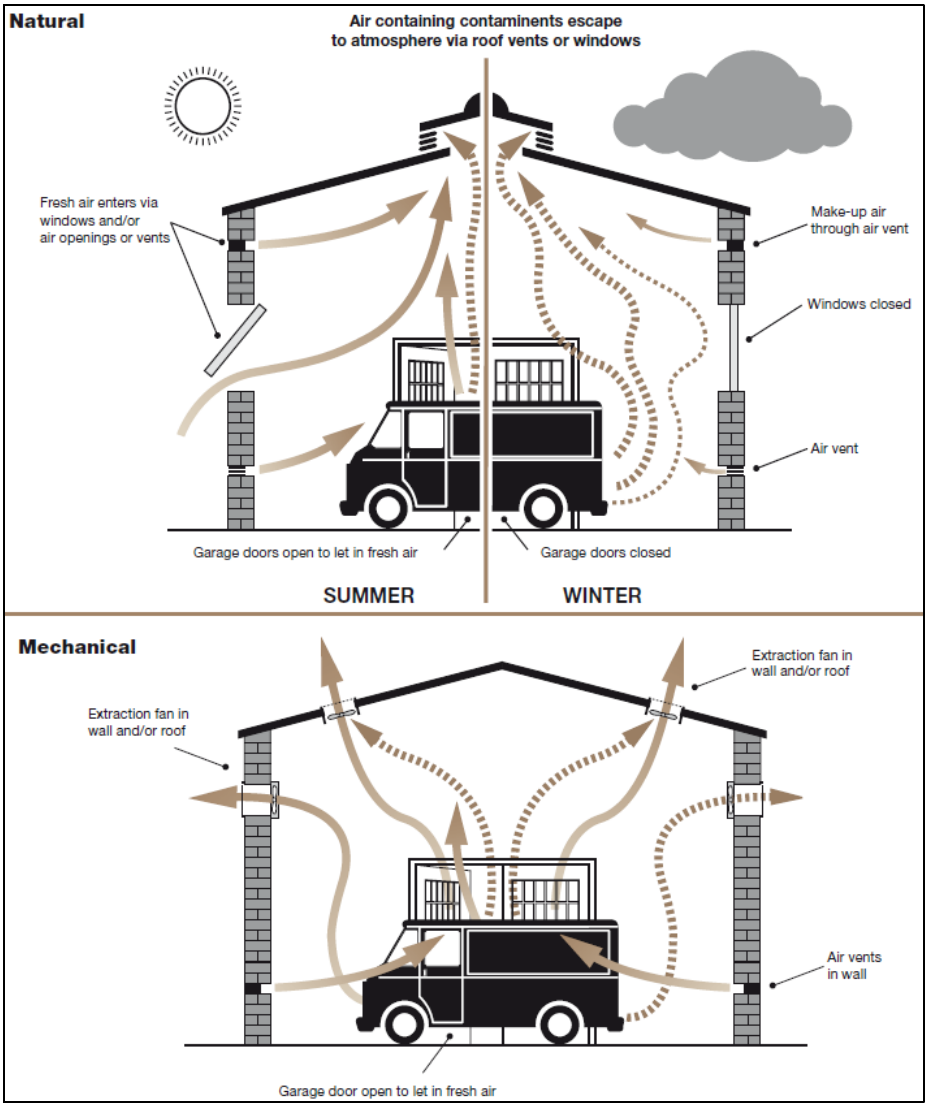

Figure 11: Natural and mechanical ventilation in a garage

Source: HSE, (2012a, p. 13).

Compared to local exhaust systems, dilution ventilation systems and local extraction ventilation systems do not capture diesel emissions at their source (e.g., the machine tailpipe) and, thus, some diesel emissions may remain in the work environment.

Given the limitations of respective exhaust systems, a combination of a local extraction ventilation system with other ventilation systems, such as a tailpipe exhaust extraction system is recommended (HSE, 2012a). However, to be effective, ventilation systems, must be properly designed and managed. They are only effective when vents and openings are not blocked and kept clear. Also, the system should be designed to ensure that polluted air is not be re-circulated back into the worksite, for example by being extracted close to a compressor which supplies fresh air to the worksite (Safe Work Australia, 2015b)

Other engineering control measures could include diesel emissions ‘after treatment’ systems (HSE, 2012a, BAuA, 2009). These could include catalytic converters to oxidise biologic gases and substances, or non-catalysed and catalysed particulate traps to take particulate matter out.

It is also important that the number of vehicles operating in a specific area does not exceed the capacity of the ventilation system to ensure that it continues to work as designed (OSHA, 2013). For instance, general ventilation may only be suitable for a small workshop with one or two vehicles (Safe Work Australia, 2015b).

A separation of areas in which diesel engines are operating or where different levels of exposures occur should also be considered to reduce the exposure for workers (Safe Work Australia, 2015b, BAuA, 2009). This can be achieved through a modification of the layout of the workplace by separating the area where diesel engines are operating from the rest of the workplace (Safe Work Australia, 2015b).

Workers in close proximity to diesel-producing machines or vehicles and workers who are working in enclosed cabins (e.g. in vehicles) should also be provided with filtered air (Hedges et al., 2007).

Fresh air can be provided by using an enclosed cab filtration system. For example, the US National Institute for Occupational Safety and Health (NIOSH) tested a cab filtration system that used a mixture of three filters to reduce equipment operators’ exposure to dust and diesel particulates. A field assessment showed that three out of four tested filtration systems achieved a protection factor which was higher than 1.000 using the particle counting method. The fourth filter had a lower performance which was attributed to a damaged filter (Organiscak et al., 2013).

The two bottom layers of the hierarchy of control represent measures that rely for their effectiveness on human behaviour, for example providing exposed workers with training or prescribing particular work methods or health and safety rules in safe work procedure documents.

Administrative controls for risk of exposure to diesel engine emissions include reducing the number of workers who are directly exposed to diesel engine exhaust and/or reducing the duration of their exposure through modifying work schedules or introducing a job rotation scheme (HSE, 2012a, OSHA, 2013, Safe Work Australia, 2015b).

Also, safe working methods should be specified in site rules or procedures. These include establishing a requirement that all diesel exhaust emitting machinery engines are switched off when they are not required for a substantial period of time (HSE, 2012a).

The generation of diesel engine exhaust can also be reduced by prohibiting unnecessary lugging or idling of engines (OSHA, 2013). OSHA (2013) recommends restricting the quantity of diesel-powered equipment and total engine horsepower operating in a determined area the total number of which should not exceed the capacity of the ventilation system. The Australian Institute of Occupational Hygienists recommends a control of Diesel Particulate Matter to below 0.1 mg/m^3 as an 8 hour time weighted average value as an exposure limit for workers (Australian Institute of Occupational Hygienists, 2013).

Establishing one-way traffic routes and speed limits can also reduce the level of traffic and diesel exhaust emissions in a work area. Where possible, OSHA recommends the establishment of areas and access routes without any diesel engine operation for personnel travel (OSHA, 2013).

A rigorous, regular maintenance regime is also recommended for the control of diesel exhaust emissions (BAuA, 2009, HSE, 2012a, Karpinski, 2015, OSHA, 2013). This includes cleaning and/or replacement of air filters and regular tuning of diesel engines. Emissions should be monitored and backpressure on exhaust treatment devices should be recorded at the time of each routine service (Hedges et al., 2007). Hedges et al. (2007) suggest a time frame between 4,000 and 8,000 hours as the maximum operating time before older diesel engines are subjected to a general overhaul.

Workers should be informed about diesel engine exhaust and given instructions relating to the proper use of personal protective equipment (respiratory equipment) (Karpinski, 2015). Training in languages other than English may be necessary in the diverse construction industry workforce.

Workers exposed to diesel exhaust emissions should use respiratory protection (OSHA, 2013). Considering the health risks of diesel particulates, half or full-face respirators with a filter cartridge are more suitable than P2 disposable respirators. P2 disposable respirators may be more suitable if the concentration of vapour in the diesel exhaust is low (Safe Work Australia, 2015b). However, respiratory protection is only effective if it is worn correctly. Therefore, fitting tests and clear instructions about how to fit respiratory protection is essential. A clean shaven policy should also be implemented.[2]

2 Further details about the effects of stubble on the effectiveness of respiratory protection can be found in the PPE section for control measures for airborne hazards.

8.2 Control measures for airborne hazards

Dust, including silica, can be found in a variety of construction works (Workplace Health and Safety Queensland, 2013). Silica dioxide occurs in different forms and is mostly found in quartz. The term silica is commonly used for crystalline silica and crystalline quartz. Exposure to respirable silica is an important risk factor for developing respiratory diseases and lung damage. Respirable silica particles, which are usually smaller than 10 µm, cannot be seen by the naked eye (Workplace Health and Safety Queensland, 2013). Studies found evidence that crystalline silica is carcinogenic and is a causal factor for several lung disorders, even though the risk of developing cancer is influenced by other (biological and genetic) factors (Workplace Health and Safety Queensland, 2013).

Thus, any process that creates dust with materials containing quartz can be hazardous to workers. To reduce dust, especially silica dust, exposure standards have been implemented. The limit for silica dust exposure in Australia is 0.1 mg/m^3 (Cancer Council Australia, 2017a). The Occupational Safety and Health Administration (OSHA) Standard in the US, which was implemented in September 2017, establishes an even lower exposure limit of 50 $\mu g/m^3$ (micrograms of silica per cubic meter of air) over an eight-hour work day. If the exposure limit is higher than 25 $\mu g/m^3$ over a control period of eight hours, employers in the USA are required to implement an air monitoring program (OSHA, 2018).

Exposure concentrations are measured using personal sampling methods and should include a minimum number of samples to ensure results are statistically valid. Given that exposure limits are based on personal exposure for an 8 hour shift, the preferred approach to measure the exposure limit is personal dust sampling (Occupational Health Services Australia, 2017). For instance, air sampling pumps may be used to assess the dust exposure levels experienced by individual workers (for personal exposure).

Other tools have also been used to analyse dust exposure levels. One example is the Enhanced Video Analysis of Dust Exposures (EVADE) software program which was developed by the US National Institute for Occupational Safety and Health (NIOSH). EVADE is a software which merges video files and logged data files from a real-time dust monitor to identify sources of exposure and can be used in conjunction with Helmet-CAM, a video camera that is worn by the worker to track a record of their activities (NIOSH, 2014).

According to the hierarchy of control, the most effective measure for controlling the risk of dust exposure is to eliminate dust, especially silica dust, from the work environment.

However, this is not always feasible because dust occurs in many different construction tasks, such as concrete block cutting or grinding, drilling rock or tunnelling. Thus, is often not possible to eliminate dust, especially when working with sand or concrete, or when undertaking tunnelling activities (Workplace Health and Safety Queensland, 2013).

The next level of control according to the hierarchy of control is substitution, which would include the replacement of a hazardous material or process with something less hazardous. Substitution controls for dust include: substituting sand for garnet, staurolite or ilmenite for abrasive blasting, or replacing silica powders with aluminium polishing powders or non-silica powders (Workplace Health and Safety Queensland, 2013).

Work processes can also be changed to reduce the risk of exposure to dusts. For example, using wet processes instead of dry ones or vacuuming instead of sweeping to reduce dust (Workplace Health and Safety Queensland, 2013).

Engineering controls to prevent workers from dust can be divided into three different categories: Containment, ventilation and suppression.

Containment is the most effective of these engineering controls because it prevents silica dust from entering the workplace, for example using an abrasive blasting chamber (Workplace Health and Safety Queensland, 2013). However, containment is sometimes not practicable or possible.

If dust cannot be contained, ventilation can be used as a control measure. Ventilation systems are available in three types:

(i) local exhaust ventilations
(ii) natural ventilation, or
(iii) forced dilution ventilation (Workplace Health and Safety Queensland, 2013).

Local exhaust ventilations (LEV) are the most effective ventilation systems to control a large amount of dust. In some circumstances, where it is most effective, LEV can render respiratory protective equipment unnecessary (Workplace Health and Safety Queensland, 2013). Three different types of LEV's are available (Workplace Health and Safety Queensland, 2013):

- enclosing hoods
- high velocity low volume hoods, and
- exterior hoods

Enclosing hoods are suitable when work is conducted in a fully (or almost fully) enclosed worksite. The exhaust system in the enclosing hood contains the dust. High velocity low volume hoods are specialised capturing devices which are attached to tools at the source of the dust.

Exterior hoods produce airflows by inducing a negative pressure above the hood boundary. However, exterior hoods are only effective when they are close to the dust source. Exterior hoods, on the other hand, are special devices which are attached directly to the source of dust (Workplace Health and Safety Queensland, 2013).

The most suitable type of LEV depends on factors including the task itself, the source of dust (particularly if it is a point or diffuse source), the amount of dust, and its concentration.

Different studies have been conducted to analyse the effectiveness of different types of LEVs. For example, Shepherd et al. (2009) tested the efficacy of LEV combinations on hammer drills. They considered the reduction effects on inhalable, thoracic and respirable dust concentrations[3]. The results of their study show a reduction of the amount of inhalable, thoracic, and respirable dust by more than 80 per cent when a combination of a hood and vacuum source was used. Moreover, the respirable dust concentrations were reduced from 3.77 mg/m^3 to 0.242 - 0.370 mg/m^3. Further, the thoracic dust concentration was reduced from 12.5 mg/m^3 to 0.774 - 1.23 mg/m^3. The inhalable dust concentration was also reduced from 47.2 mg/m^3 to a concentration range of 2.13 - 6.09 mg/m^3. They also measured silica concentrations and the extent that these were reduced by the various LEV combinations. Silica concentrations were reduced from 0.308 mg/m^3 to a range of 0.006 - 0.028 mg/m^3 in the respirable size fraction. The thoracic size fraction was reduced from 0.821 mg/m^3 to 0.043 to 0.090 mg/m^3 and the inhalable size fraction was reduced from 2.71 mg/m^3 to 0.124 to 0.403 $mg/m^{3.}$

The results of the study highlight that LEVs fitted to hammer drills can significantly reduce the amount of respirable dust by an average of 85 per cent, the airborne concentrations of respirable silica even by 94 per cent. There were no statistically significant differences in the dust concentrations between the different types of LEV tested, even though the respirable dust concentration was a little bit higher using the bellows hood-large vacuum source (Shepherd et al., 2009).

Vacuum cleaners can also be helpful to reduce dust. However, it is important to select a suitable vacuum cleaner. It is suggested that vacuum cleaners which use bags are less effective for tasks where large amounts of debris occur (Echt, 2013). In these cases, cyclone-type vacuums are more effective to prevent the filter from clogging and to sustain an effective air flow rate. Even though cyclone-type vacuum cleaners are more expensive initially, they are more efficient in the long run because new bags do not need to be frequently purchased and costs associated with downtime while changing bags are eliminated (Echt, 2013).

3 Inhalable fractions are inhaled through mouth or nose. Thoracic and respirable fractions are as those fractions of inhaled particles that are capable of passing beyond the larynx and ciliated airways (Brown et al., 2013).

Case study 4: Canopy curtain to provide fresh filtered air

Canopy curtain to provide fresh filtered air

The US National Institute for Occupational Safety and Health (NIOSH) designed a canopy curtain to reduce mining roof bolter operators’ exposure to airborne respirable hazards (dust) by providing fresh filtered air to the workplace. Test results of the effectiveness of the canopy curtain show reductions of respirable dust between 67 to 75 per cent when the operator is working directly beneath the canopy (List & Beck, 2012). The original curtain has gone through some changes. An equipment manufacturer incorporated the curtain into its roof bolting machines. However, initial results of laboratory tests show considerably lower dust control effectiveness than the original curtain designed by NIOSH between (Reed et al. 2016, 2017).

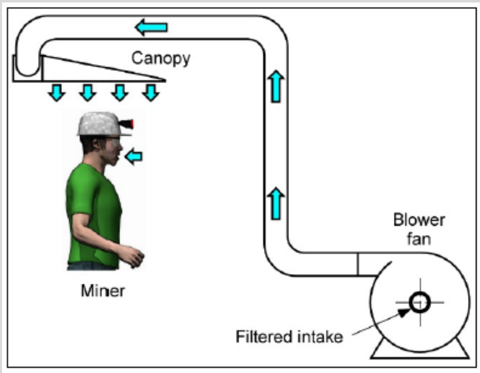

Figure 12: Canopy air curtain components

Source: Reed et al. (2016, p. 1).

Air-and-water spraying systems have been used to control dust in mines and tunnels. Dust clouds can be controlled using water or fine mist suppression (Workplace Health and Safety Queensland, 2013; Yale Environmental Health & Safety, 2009). It is estimated that air-and-water spraying systems can reduce the concentration of airborne dust by up to 80% (Prostański, 2013).

If work is conducted outdoors, additional water dust suppression is also recommended during dry weather (Yale Environmental Health & Safety, 2009).

However, it is important to use a suitable spray type to reduce dust effectively. Different spray types are presented in Figure 13.The suitability of each spray type depends on the particular task, environment and application.

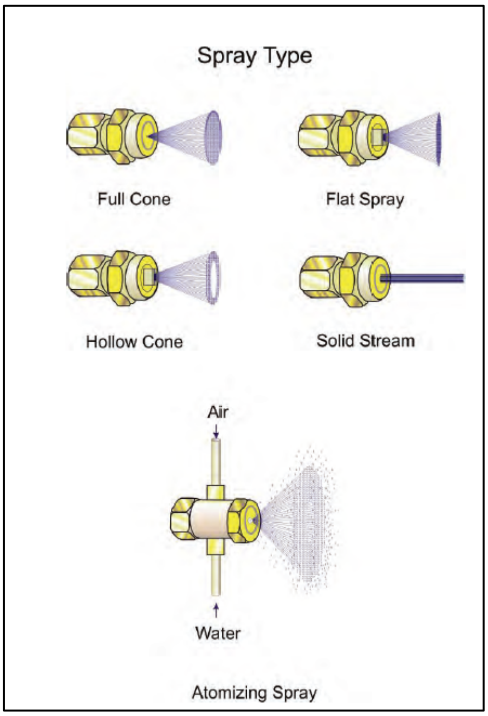

Figure 13: Spray types

Source: Colinetet al. (2010, p. 42).

For example, hollow-cone sprays can effectively redirect dust away from workers and for dust knockdown, while full cone spray nozzles are suitable for belts transfer points (Colinet et al., 2010, Cole, 2016).

Cole (2016) states that air-atomising spray rings can be used for dust control. Air-atomising spray patterns come in two different designs: Air-assisted and hydraulic. However, air-assisted nozzles have the advantage that they produce very small droplets. On the other hand, they are the most expensive sprays and complex to install (Colinet et al., 2010).

The effectiveness of dust suppression also depends on the spraying method and environmental factors, like the temperature and whether other dust suppressants are in use.

Shepherd and Woskie (2013) who compared dust concentration while cutting concrete pipes under wet and dry conditions. The amount of respirable created when cutting under dry conditions exceeded the wet water-based control measures by more than tenfold. The use of water during cutting reduced the respirable dust concentration by 85 per cent. These results highlight the importance of water-based control measures while working with concrete and brick.

Further, research suggests that the effectiveness of water-based controls can be improved using chemical suppressants in conjunction with spraying.

For example, Xu and Pei (2017) analysed the effectiveness of dust-suppression operations, testing the preparation conditions for a dust suppressant made out of calcium magnesium acetate, glycerine, sodium dodecyl benzene sulfonate (as the surfactant), and sodium hydroxide (as the initiator).

Sodium carboxymethyl cellulose has a strong crosslinking function which allows the dust suppressant to fully contact with the soil surface. Glycerin can form a water-retention layer by absorbing moisture from the air, whilst sodium dodecyl benzene sulfonate can reduce water surface tension. It allows available moisture to moisten the particles and to aggregate on the surface layer more effectively (Xu & Pei, 2017).

The dust-suppression performance was measured by four independent parameters: hardness, water retention rate, viscosity, and antiwind erosion. The results show, that that the best performing dust suppressant was prepared at a temperature of 70°C.

Furthermore, Xu and Pei (2017) tested the effects of different spraying methods. Spraying the dust suppressant instantly after water spraying worked best. This method increased the water-saving efficiency by up to 92.6 per cent. The economic cost of dust suppression using the chemical suppressant was reduced by 55.1 per cent compared to the use of a water-spraying method on its own. These results highlight the potential cost benefits associated with the selection of appropriate dust suppression methods and materials.

Notwithstanding the widespread use of water-based dust suppression, research also shows that fitting tools with local exhaust ventilation systems can produce equivalent and sometimes improved performance in reducing respirable dusts. For example, Meeker et al. (2009) analysed the ability of different block- and brick-cutting tools to reduce dust. Specifically, they tested a handheld electric abrasive cutter equipped with a LEV shroud and two stationary wet saws (the handheld cutting tool was a Bosch model 1364 12-inch abrasive cutter and Bosch 12-inch all-purpose diamond blade) with a Bosch 1605510215 dust extraction guard and other equipment. The results, based on personal breathing-zone air samples with and without the use of LEV or the water suppression, indicate that the Bosch LEV shroud vacuum cleaner was able to reduce quartz exposure emanating from the cutting tools by 96.2 per cent while block cutting. Further, this device was more effective than the tested stationary wet saw, which reduced 90.7 per cent of the dust. During brick cutting the Bosch abrasive cutter fitted with the LEV reduced respirable quartz by 91.1 per cent of the respirable quartz. This compared with 90.6 per cent reduction produced by a target stationary wet saw (Meeker et al., 2009).

Akbar-Khanzadeh et al. (2007) similarly examined different grinding methods for concrete. Akbar-Khanzadeh et al. (2007) measured the effectiveness of wet grinding as a method to reduce dust and ventilated grinding to reduce crystalline silica dust by taking air samples. They found wet grinding reduced the amount of respirable crystalline silica dust by 98.2 per cent and the amount of respirable suspended particulate matter (RSP) by 97.6 per cent. However, the LEV was even more effective by reducing the concentrations of respirable silica dust by 99.7 per cent and respirable suspended particulate matter by 99.6 per cent (Akbar-Khanzadeh et al. (2007).

When tunnel boring machines (TBMs) are used dust is controlled by capturing dust at the point of the origin and by water or foam which is brought through a rotary union where it is distributed to equally-spaced spray nozzles. Wetting is important for the control of dust while using TBMs to ensure that dust particles stay attached. However, Langmaack et al. (2010) highlight that foam works better than water for dust control. Foam provides a reduction of dust by 20 to 60 per cent compared to water. Moreover, the amount of water that is necessary to produce the foam is lower than for water spray. When compared with water sprays at a belt transfer point, high-expansion foam reduced the dust by an additional 30 per cent. Even though foam reduces the amount of water, the cost of the foam is very high. In addition, when foam is used, some modifications of the TBM are necessary. Firstly, a foam system needs to be installed. Secondly, specially designed foam nozzles on the cutter head are necessary to inject the foam, and a rotary coupling instead of the normally installed water splitter box is required to ensure specific outputs per foam injection. As such, the installation of the rotary coupling during the design of the TBM it is recommended to avoid later upgrading costs (Langmaack et al., 2010).

Furthermore, Cole (2016) and Crossrail Ltd. (2017) recommend the following engineering controls to reduce dust exposures when TBMs are used:

- employ local ventilation systems or use dampeners and registers to increase the air flow to low-velocity areas and dead areas of the TBM
- use hard ducting to supply fresh air to the ring build area in front of the TBM, and
- after TBM ring construction use precast concrete invert panels rather than concrete paving.

After engineering controls, administrative controls should be implemented to reduce dust exposures. These may include establishing warning signage and maintaining good housekeeping, but also restricting the time that workers are exposed to dusts, for example by implementing a job rotation scheme to reduce the time spent in the dusty areas (Workplace Health and Safety Queensland, 2013).

Machines and tools should also be maintained and cleaned regularly. This includes the regular cleaning of ventilation systems to ensure that they operate correctly, and to prevent the development of leaks, diminished fan performance or filter blockages (Workplace Health and Safety Queensland, 2013). Where conveyor belts are in use in a workplace, they should be washed regularly. The installation of conveyor belt wash boxes to clean them is also recommended (Cole, 2016).

Some dust generating tasks, such as dry brush sweeping, and the use of compressed air or reuse of vacuum filters should not be performed. Instead, dust should be removed by using an industrial high-efficiency particulate air filter vacuum (Cancer Council Australia, 2017a).

Health monitoring should be conducted regularly according to regulation 50 of the Work Health and Safety Regulation 2017 (New South Wales Government, 2018). Crossrail Limited in the UK (2017) introduced a health surveillance program which included lung test functions every two months for workers who are exposed to the highest levels of dust (Crossrail Ltd., 2017). Results are shared with the line manager and the worker should be referred to a lung respiratory specialist or a GP if the lung function test shows impairment.

Pulmonary function preservation interventions using periodic spirometry data and other data sources such as questionnaires should also be integrated into existing occupational health programs as part of a broader disease prevention strategy.

Hnizdo et al. (2011) analysed the effectiveness of a pulmonary function preservation intervention which was integrated into an on-going worksite wellness program for heavy-construction workers in the US. The prevention strategy included an occupational safety assessment and safety measures to prevent exposures. It included also a disease management and different lifestyle interventions such as weight and smoking control.

Each worker had an individual intervention plan including longitudinal data, based on annual questionnaires, occupational history, weight changes and smoking habits. The workers were supported by health coaches who supported behaviour changes and workplace safety officers who focused on occupational exposure and prevention of exposures.

The results of their study using a sample of 1,224 workers with a five year or more follow-up indicate that longitudinal spirometry may help to motivate workers to stop smoking and / or support the employer to reduce exposure to respiratory hazards. Hnizdo et al. (2011) highlight that a periodic spirometry can be useful for respiratory disease prevention. The computerised approach to longitudinal data management and its evaluation can involve different stakeholders. Health care providers can monitor longitudinal data across groups and individuals, which in addition, can lead to a greater understanding of the changes occurring over time. Moreover, reviewing the longitudinal spirometry and questionnaire data helps physicians to screen for a subgroup of workers who show excessive decline in lung function. Taking into account the rate of decline and the rate of lung function the risks of future impairment can be predicted. Hnizdo et al. (2011) highlight also that an integration of a respiratory disease prevention in ongoing programs may be more effective than isolated programs.

Depending on their tasks, workers should wear appropriate personal protective equipment such as particulate filters to remove liquid particles or finely divided solid from inhaled air. The prefix 'P' followed by a number indicates the filtration efficiency, with:

- P1 filters are for mechanically generated particulates like silica or asbestos
- P2 filters are for thermally and mechanically generated particulates like metal fumes
- P3 requires a full-face mask and can be used for all particulates including highly toxic materials like beryllium (The University of Western Australia, 2016).

Cole (2016) refers to the use of Full-face P3 Powered Air Purifying Respirators for shotcretors and other workers who are located within a shotcreting exclusion zone or other high exposure areas.

Workers should also be trained on the proper use of their personal protection equipment to ensure its effectiveness (Workplace Health and Safety Queensland, 2013), whilst the correct material and pore size of face masks should also be evaluated. Even if the right filter masks are used, their effectiveness may be reduced by other factors such as facial hair stubble. Frost & Harding (2015) analysed the influence of stubble on the effectiveness of P3 filtering face pieces and half masks on a male sample (n=15). Repeat fit tests were conducted over one week with men starting with a cleanly shaved face at the beginning of the testing.

The effectiveness of the analysed face pieces and half masks was negatively influenced if stubble was present (Frost and Harding, 2015). The inward leakage for some face pieces increased by between 3 - 6 per cent by the end of day 4. Moreover, a prediction of the inward leakage by the 7th day showed an unacceptable level (greater than one per cent) for all face pieces tested. Frost & Harding’s (2015) study highlights that tightfitting facepieces are not effective when workers are not clean shaven.

Asbestos

Particular care should be taken when working with asbestos. Even though asbestos was banned on the 31st December 2003, it was used in more than 3000 different products in Australia. As such, workers may still be exposed to asbestos, especially during demolition works. Workers who are not trained in handling asbestos (or hold a licence) must not handle asbestos (Safe Work Australia, 2018b).

Moreover, an asbestos register has to be prepared unless

- no asbestos is likely to be present at the workplace
- no asbestos has been identified, or
- the work is being conducted in a building which was constructed after asbestos was banned end of 2003 (Safe Work Australia, 2016c).

In addition, WHS Regulations require an asbestos management plan for the site where asbestos is identified as contaminating a workplace (Safe Work Australia, 2016c).

The risk of asbestos can be reduced by a variety of controls. The control measures are similar to the airborne control measures, and include for example the following:

- use of dust suppressions by using water sprays
- use local exhaust ventilations
- use wet drilling (Safe Work Australia, 2016c)

Engineering controls could be as simple as applying a small amount of silicon or another type of paste to the surface of an asbestos cement sheet where a hole is to be drilled. The paste will collect loose fibres when the drill bit goes though the sheet and prevent particles from becoming airborne. After the drilling is finished, the paste can be wiped clean with a rag (Safe Work Australia, 2016c).

A more comprehensive type of control could be the use of a mini-enclosure which isolates the source of asbestos fibres. The mini-enclosure can be combined with an extraction fan to capture and remove airborne fibres from the air (Safe Work Australia, 2016c).

For any kind of demolition work, it is also important that dust generated does not intrude into other areas. Any kind of asbestos-related work area has to be separated from other work areas at the workplace. Moreover, appropriate signage is to be used to indicate where asbestos-related work is being carried out and barriers should be used to separate the work area (Safe Work Australia, 2016c). Areas close to extensive dust-generating work should be demarcated and the following control measures should be considered to prevent dust within (indoor) work areas;

- implement barrier protections at the entrance to the working area and use sticky floor mats to reduce the amount of dust or debris transferred to any other working areas (Yale Environmental Health & Safety, 2009)
- use mining equipment (air-conditioned cabins with filtered air) (Safe Work Australia, 2016c)

- use thickened substances such as pastes and gels to cover the surfaces of asbestos being worked on (Safe Work Australia, 2016c), and
- use shadow vacuuming (Safe Work Australia, 2016c).

In the case work of outdoor work, dust-generating activities should be avoided on high wind days (Yale Environmental Health & Safety, 2009). Construction debris should also be removed from site locations through an approved route, if possible during off-peak or non-work times. Waste materials should be covered and netted to prevent dust generation during removal and haulage (Yale Environmental Health & Safety, 2009). Covers should also be installed over conveyors where a high airflow might dry out spoil allowing dust particles to become airborne (Cole, 2016).

Drinking, eating and smoking is forbidden while working with asbestos (AUVA, 2015) and washing facilities should be provided (Safe Work Australia, 2016c) as close as possible to the working area. Workers should also be provided with mild skin cleansers and use soft paper or towels for drying. Very abrasive cleansers should be avoided as their use can lead to the development of dermatitis (HSE, 2015).

Regulation 435 of the Work Health and Safety Regulations 2017 (New South Wales Government, 2018) requires a person undertaking or conducting a business to ensure that health monitoring is provided to workers carrying out the work. Health monitoring must include a physical examination of the worker with a focus on the respiratory system. This includes a respiratory function test unless another form of health monitoring is recommended by a medical practitioner (Safe Work Australia, 2016c). The Austrian Social Insurance for Occupational Risks (AUVA) (2015) recommends medical check-ups of the lung function every two years and a lung x-ray every four years for workers are exposed to asbestos.

Samples of asbestos containing material should also be collected and analysed.

In addition to other control measures, PPE is necessary when working with asbestos. This includes coveralls, respiratory protective equipment, footwear and gloves. The selection of suitable PPE depends on the nature of the asbestos work. Any kind of respiratory protective equipment should comply with AS/NZS 1716-2003 Respiratory Protective Devices and be selected, used and maintained in accordance with the AS/NZS 1715-1994 Selection (Safe Work Australia, 2016c).

Other types of PPE should be considered. AUVA (2015) recommends using closed eye goggles for any kind of overhead or demolition work and workers should be provided with gloves and hand protection creams (AUVA, 2015). If workers wear disposables shoe covers or overalls, they should be removed before leaving the working area. If workers do not wear any covers they should clean their shoes and clothing before leaving (Yale Environmental Health & Safety, 2009, AUVA, 2015). In the case where clothing may be contaminated with particles of asbestos, workers should vacuum clean their clothes (AUVA, 2015).

The number of workers accessing the work areas can also be limited, for example by restricting access using electronic passes. Additional H&S training or awareness programs can also be used to increase workers understanding of the risk with a specific task, environment or material-related activity.

8.3 Control measures for noise

Controlling noise during construction works may be difficult for contractors because construction activities do not always take place in a single isolated location and may not be stationary (Laborers Health and Safety Fund of North America, 2014).

Construction often occurs outside and is therefore affected by several conditions such as weather, topography and/or landscaping. Equipment and machines which produce noise often move during a work day and as a consequence, the intensity of their noise level varies throughout the work day.

The most effective way to protect workers from noise exposure is to eliminate the source of noise. Noise elimination includes avoiding the usage of noisy machines or processes or moving noisy operations away from other work activities (IOSH, 2018).

Noise levels can also be lowered by using different controls.

Substitution strategies include replacing noisy equipment or machines with quieter ones. Table 8.1 provides an overview of substitutions of different machines and equipment to reduce noise.

Table 8.1: Substitution of work machines and equipment

Source of noise	Alternative
work machines and equipment	
solid wheels	rubber tyres
fuel engines	electrical engines
rollers	conveyor belts
metal chutes and containers	rubber or plastic chutes and containers
pneumatic tools	electrical tools
metal gears	plastic gears
metal bearings	fibre bearings
rolling bearing	slide bearing
impact wrenches	hammer drill

Source: IOSH (2018) and OIR & WorkCover Queensland (2017).

The aim to reduce sound levels may also be achieved through buying quieter diesel generators. New types of diesel generators are designed to emit low noise and vibration which leads to a reduced noise level up to 15 dB(A) compared to older diesel-powered generators. They are also quieter than most gasoline sets and units which are totally enclosed and damped, including cooling, exhaust and intake systems (LHSFNA, 2014).

Substitution strategies may include modification to working methods or proceedings to reduce noise as detailed in Table 8.2.

Table 8.2: Substitution through a modification of working methods

Source of noise	Alternative
working methods	
riveting	welding
discharging	evacuating
flanging with a hammer	using a Kraft former machine
using a nibbling machine	using a laser cutting machine
acoustic signalling	optical signalling
marking the punching unit with a punch	using a centre to punch
hammering	gluing
stapling	clipping
chipping	grinding
forging	pressing

Source: IOSH (2018), BGHM (2013) and OIR & WorkCover Queensland (2017).

Modifications of tools and machines can also help to reduce noise. For example, an average front end loader has a typical noise level of 95-102 dB(A) at the position of the operator (assuming a noise control cab is not fitted). The noise level can be reduced by a noise control cab or adding sound suppression to an existing cab. Whereas both methods can reduce the noise level by 82-90 dB(A) the cost of adding sound suppression to an existing cab is much lower ($ 500-1,000 US or AUS $635 – 1,270) compared to installing a noise control cab ($ 12,000-15,000 US or AUS $ 15,232 – 19,040)[4]. However, replacing the exhaust system of a front-end loader can reduce noise emissions by 90-100 dB (A) and has a relatively low associated cost of between $200 – 400 US (AUS $254 – 502) (LHSFNA, 2014).

Sound dampening mats are also effective to reduce sound levels inside operator caps. Salah et al. (2017) evaluated the technical effectiveness and practicality of sound dampening mats as sound barriers inside heavy-equipment engine compartments. Sound pressure levels inside the operator cabs were significantly reduced by 5.6 - 7.6 dB(A) on the full-throttle setting. Such mats are affordable, simple to install and significantly reduced the engine noise reaching the operator (Salah et al., 2017).

Tool modifications may include adding vibration isolation mountings, mufflers, laggings and silencers to existing machines or equipment where possible (IOSH, 2018, Safe Work NSW, 2018a, OIR & WorkCover Queensland, 2017). As an example, pneumatic nail guns have an average sound level of 94.5 dB (A).

4 Estimated cost for noise control cab with airconditioning.

The sound level can be reduced by improving the existing muffler and incorporating some type of exhaust or return line to 75.5 dB (LHSFNA, 2014)

It is also recommended to provide wear-resistant rubber or plastic coatings to reduce acoustic sounds and to stiff and fix damping materials to panels or other surfaces to reduce the noise impact of these items during processing (Safe Work NSW, 2018a, OIR & WorkCover Queensland, 2017). For example, the use of damping concepts for rotating circular saw blades have been documented such as in Pohl and Rose (2016).

Acoustical silencers should be implemented in intake and exhaust systems (such as internal combustion exhaust systems or air conditioning systems) (Safe Work NSW, 2018a, OIR & WorkCover Queensland, 2017, IOSH, 2018).

The exposure for the workers can also be reduced by separating the noise using noise barriers and sound-reducing enclosures that fully enclose machines or sources of noise (IOSH, 2018, Safe Work NSW, 2018a, OIR & WorkCover Queensland, 2017). If containers are being used to move materials or to remove debris the German Metals and Wood Trade Association (BGHM) (2013) suggests using wire containers with closed meshed steel plates instead of steel sheet containers to reduce sound levels.

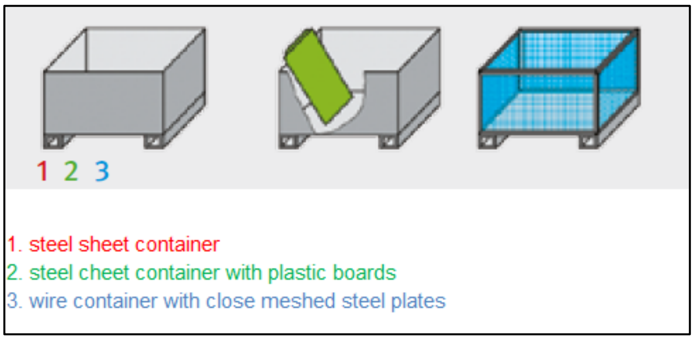

Figure 14: Sound level reducing container

Figure adapted from BGHM (2013, p. 35).

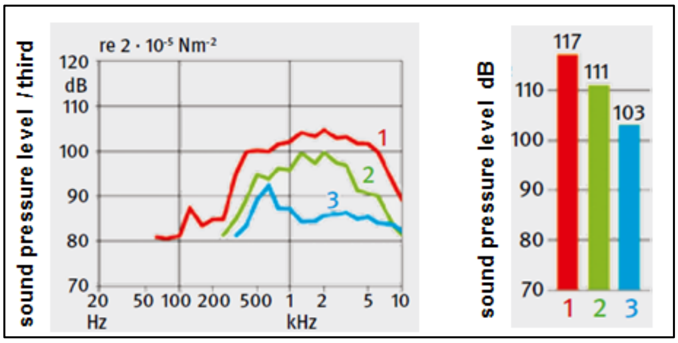

Figure 15: Sound level and third octave spectra of each container

Figure adapted from BGHM (2013, p. 35).

Figure 15 shows the sound level and third octave spectra level of each container on the left, whereas the right side on the right presents the sound level while pieces were throwing into the container.

Purchasing equipment, which produces lower sound level should also be considered as part of the purchasing policy which features as introduction for control interventions on the administrative control level (IOSH, 2018, Safe Work NSW, 2018a, LHSFNA, 2014). Those responsible for making purchasing decisions should liaise with occupational health and hygiene professionals to understand the implications for the specification of plant and equipment on worker exposure levels to noise.

For example, Figure 16 highlights factors to consider when buying saw blades to reduce noise exposure.

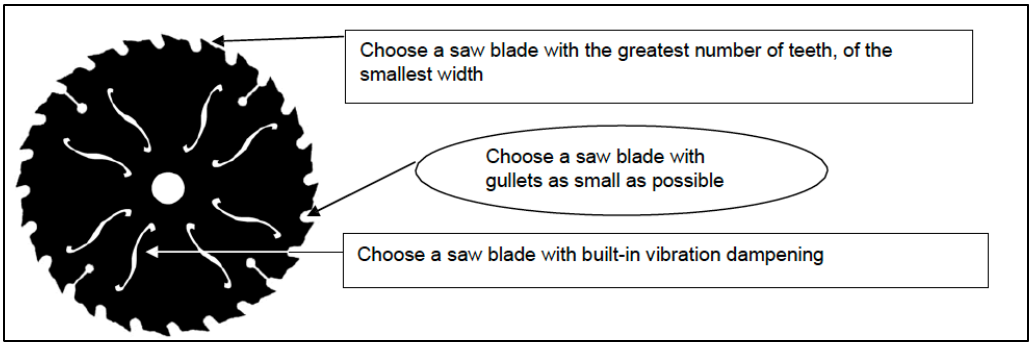

Figure 16: Considerations when purchasing quiet saw blades
Source: LHSFNA, (2014, p. 6).

Furthermore, machines and equipment should be maintained regularly to reduce noise. Worn bearings and gears should be replaced regularly (IOSH, 2018, OIR & WorkCover Queensland, 2017). Machines should also be used by an optimum speed (IOSH, 2018, OIR & WorkCover Queensland, 2017).

LHSFNA (2014) suggests implementing noise perimeter zones to limit exposure to noisy processes or equipment. Zones with noise over a specified level (85 to 90 dB (A) or more are roped off and marked. Workers who do not have to work within those areas are advised not to enter and all workers who enter the zone must wear appropriate hearing protection However, when establishing zones, it is important to take into account that noise does not radiate the same way in all directions. The dissemination of noise depends on surfaces, obstructions and other environmental factors (LHSFNA, 2014)

Work should also be scheduled according to the noise level. Noisy work should be completed at times when there are not a lot of workers on the worksite. Quiet areas for breaks should be provided.

The time workers spend in noisy areas should be restricted, for example by the implementation of a job rotation scheme (Safe Work NSW, 2018a).

When it is not possible to reduce the noise level workers should be provided with personal hearing protectors of the correct rating in accordance with Part 3 of Australian/New Zealand Standard AS/NZS 1269 (Safe Work NSW, 2018b) which can be found in Table 8.3.

Table 8.3: Hearing protector classification according to the Australian/New Zealand Standard AS/NZS 1269

Class	dB (A)
1	Less than 90
2	90 to less than 95
3	95 to less than 100
4	100 to less than 105
5	105 to less than 110

Source: Adapted from the National Occupational Health and Safety Commission (2004, p.32).

Workers should be trained in how to use and fit personal hearing protectors correctly and when to wear them (HSE, 2013, Safe Work NSW, 2018b). It is recommended to use earplugs when workers are exposed to noise levels of 85 dB (A) or if the workers have to shout in order to communicate (LHSFNA, 2014).

One of the advantages of foam earplugs is that they make deep fitting easier. Workers should be trained in which type of hearing protection is correct in particular cases and how to use them correctly considering that ear plugs can be blocked by wax or ear plugs can be pushed against the ear canal wall HSE (2013). Appropriate monitoring and supervision is also recommended to ensure that hearing protection is correctly used (OIR & WorkCover Queensland, 2017, Safe Work NSW, 2018b).

However, as with other forms of personal protective equipment, hearing protection is only effective if it is used correctly. Therefore, although it should be a requirement in noisy work conditions, it is also considered to be the last line of defence. Importantly all efforts to reduce the levels of noise in the work environment that are reasonably practicable should also be taken.

8.4 Control measures for heat

Homeostasis is the process by which the body keeps itself in a thermal state of equilibrium. The body's internal environment (temperature, pH, blood pressure) needs to remain relatively stable achieving a core body temperature of approximately 37°C (Cramer & Jay, 2016). This equilibrium is a balance between heat exchange of the external environment and the heat that is generated by the body's internal processes of metabolic rate and physical activity. Most adverse effects arise form a failure of the body's cooling mechanisms as a result of system overload, causing a compromise of health, safety, efficiency and productivity (Parsons, 2003).

A combination of factors contributes to heat stress and include environmental factors (air temperature, humidity, wind speed and radiant heat), metabolic cost of work, and clothing requirements (Parsons, 2003). Prickly heat, heat cramps, heat syncope, heat exhaustion and heat stroke may occur, with heat stroke being life threatening and has the potential to cause irreversible damage (Parsons, 2003).

For a health risk to arise from exposure to thermal hazards, the thermal hazard must first contribute a net load upon the person above a physiologic threshold. Whether or not this occurs depends on several factors, including the combined contributions of metabolic cost of work, environmental factors and clothing requirements. The risk of heat illness usually increases with the duration, frequency and intensity of thermal exposure combined with factors that facilitate a person's heat loss proportionate to heat gain (Cramer & Jay, 2016; Parsons, 2003).

Assessment of risk of heat-related illness

Rowlinson & Jia (2015) characterise construction work as heavy physical work that results in worker physical strain and subsequent metabolic heat gain. In the construction industry, particularly in Australia, thermal heat stress has not been a well-recognised occupational hazard, regardless of trends dating back to the late 1970s indicating a positive relationship between seasonal variation in construction incident rates and observable increases during the summer months.

Rowlinson et al (2014) report the pattern of climatic heat risk at construction sites varies with project types as well as project lifecycle stage. For example civil engineering workers constructing roads are more likely to be vulnerable to radiant heat as determined by characteristics associated with bitumen road and outdoor work. Construction workers at building sites however are afforded typically more shade, yet are more likely to suffer heat stress generated by high humidity and lack of ventilation, in particular those workers installing services and infrastructure in confined building spaces or in tunnels where ambient temperatures may be elevated and the replacement of fresh air is less than adequate.

Safe Work NSW (2006) note that work involving hot temperatures can lead to a variety of symptoms ranging from physical discomfort through to conditions that are life threatening. It is therefore important to distinguish between a condition that threatens health and safety and a feeling of discomfort. Clause 40 of the Model Work Health and Safety Regulations (Safe Work Australia, 2011b) requires that workers carrying out work in extremes of heat are able to carry out work without risk to health and safety.

The selection and use of a heat stress index will inform the correlation between thermal environment parameters measured and the thermal strain experienced by the exposed person or worker group, such that exposure controls can be selected and applied (Di Corleto, Firth & Maté, 2013).

In accordance with Safe Work Australia (2013a) assessment and evaluation of thermal stress exposure to those worker undertaking construction activties can be performed in accordance with the *Australian Institute of Occupational Hygienists* (AIOH) *Basic Thermal Risk Assessment* (Di Corleto, 2013) and includes sampling of the occupational environment such that, if and where necessary, a rational heat stress indices could be selected and applied.

The Apparent Temperature (AT) index is considered to be a valuable initial indicator of the environmental contribution to thermal stress, as it is influenced by air temperature, wind speed and humidity and should be selected for use in accordance with the *AIOH's Basic Thermal Risk Assessment* as it is considered more intuitive than the wet bulb globe temperature (WBGT) index and can be calculated in the absence of technical knowledge (Cramer & Jay, 2016).

There is no definitive exposure standard or limit for heat stress as individuals respond to heat in different ways as a range of individual and environmental factors can lead to heat stress in various situations. Therefore, it is ultimately up to each company to assess, evaluate and control exposures that are likely to influence heat stress in workers.

Parsons (2006) states that whether a hot environment should be considered safe or not depends on the range and types of action that workers can take to reduce their exposure, also called 'adaptive opportunity'. Parsons (2006) argues that environments with the same thermal characteristics may have very different adaptive opportunities and therefore pose different levels of risk.

Adaptive opportunities will vary according to the nature of work, but could include actions such as:

- reduction of work speed
- ability to move away from the heat
- availability of shade, and
- ability to switch on a fan or open a window to provide ventilation.

Risk controls for heat (thermal load)

Risk controls for heat exposure are embedded in enterprise agreements entered into by workers in the Australian construction industry. The Construction, Forestry, Mining and Energy Union Enterprise Agreements state that workers will stop work and leave site when the temperature reaches 35 degrees (CFMEU, 2015).

At temperatures below 35°C, the agreement also states that workers are to be relocated out of direct sunlight where the work environment creates a serious risk to their health and safety.

Employers are to provide:

- sun screen
- cool clear drinking water
- air-conditioned site sheds
- hard hat brims, and
- sunglasses where required.

Construction workers are also advised to:

- drink 100-200ml of water at regular intervals and not allow themselves to become thirsty
- avoid drinking coffee, tea, alcohol and caffeinated soft drinks
- wear light coloured, loose clothing made of natural fibres wherever possible
- take regular breaks in a cool place, and
- monitor their physical condition and that of their co-workers (CFMEU, 2015).

These controls operate at various levels of the risk control hierarchy, from elimination (stopping work) to the use of protective equipment.

The avoidance of work in extreme temperatures where possible is desirable. In some countries Kjellstrom et al. (2009) report that work is scheduled in order to avoid the loss of work capacity that occurs during the middle of the day, for example, using 'siestas', night work, or similar approaches to perform work during relatively cooler parts of each 24-hour period.

Safe Work Australia (2013a) guidance material for managing the risks of working in the heat also states that persons in charge of a business or undertaking must do everything that is reasonably practicable to eliminate the risks associated with working in heat, which may include cancelling certain work tasks, rescheduling tasks to cooler parts of the day or waiting for hot conditions to pass.

Where risks cannot be eliminated, employers must minimise risks it as much as is reasonably practicable using alternative methods.

Safe Work Australia (2013a) identifies a range of controls that act on the physical work environment to make it less dangerous. These include substitution measures that reduce the extent to which workers are exposed to heat, including:

- use automated equipment or processes to access hot locations. For example, use a drone to inspect a fire ground.
- where possible, have workers do the work elsewhere. Prefabricate materials in airconditioned factories.
- install automated or remote-controlled machinery so that workers don't have to do physically demanding work by hand, and
- use plant or other equipment to reduce manual labour. For example, use a crane or forklift to lift heavy objects, or use earthmoving plant for digging.

Rowlinson et al. (2014) observe that heat can be generated by plant and machinery and suggest that, wherever possible, heat-generating plant and machinery should be replaced by plant and machinery which generates less heat.

Engineering controls can also be implemented to reduce heat exposure. For example, ventilation and improving the air flow can also help to reduce heat exposure in enclosed workplaces (Safe Work Australia, 2013a, Rowlinson et al., 2014). Surface heat exposure and the risk of heat gain can be reduced by providing shelters and/or shade structures for outdoor work (Rowlinson et al., 2014).

Areas with no or low airflow can be provided with fans and, in extreme conditions, air and water supplies can be refrigerated to enhance cooling (Safe Work Australia, 2013a). Site sheds and facilities should also be provided with air-conditioning (Rowlinson et al., 2014).

Administrative risk controls for heat exposure include the modification of work, including the specification and strict adherence to work/rest ratios (as noted above)

Safe Work Australia (2013b) recommend that persons in charge of a business or undertaking:

- organise work to minimise physically demanding tasks, for example conduct work at ground level to minimise climbing up and down stairs or ladders
- modify targets and work rates to make the work easier and reduce physical exertion
- modify uniforms or required dress codes so workers can wear cooler, more breathable clothing
- ensure workers are not working alone, or if they must work alone, monitor them and make sure that they can easily call for help, and
- establish appropriate work-rest schedules.

Yi and Chan (2013) aimed to optimise the schedule for working and resting activities for construction workers in hot and humid environments in Hong Kong. They developed a schedule which maximises productive working time and safeguards for the workers. They presented a work and rest regime which schedules a 15 minute break after a 120 minute period of working in the morning. The schedule for the afternoon contained a 20 minutes break after a duration of working 115 minutes.

In some countries and industry sectors, user-friendly resources to provide assistance to managers and supervisors in determining appropriate work-rest ratios in certain circumstances have been developed. For example, in Canada, the Ontario Fire Marshall's office has developed 'a heat stress wheel' that can be used by managers to quickly and easily determine safe work limits for firefighters during activities that involve working in different environments and wearing different levels of protective equipment (McLellan and Selkirk, 2006).

Administrative control measures for work-related exposure to heat may include establishing a job rotation system for workers who are working in hot areas (Rowlinson et al., 2014, Safe Work Australia, 2013a). Self-pacing has also identified as an autonomous control measure that workers intuitively use to manage thermally stressful conditions and reduce heat strain (Lucas et al. 2014). Some research indicates that people are able to self-pace consistently in heat as long as their compensation (pay) is unaffected by their work rate (Vogt et al. 1983; Evans et al. 1980). However, when compensation (pay) is affected by production volume, for example when working on a piece-rate pay system, Donoghue and Bates (2000) suggest that workers push themselves too hard and are at risk of heat-related illness. Lucas et al. (2014) are suggest that, under piece rate pay conditions, self-pacing can lead to working at a slower pace resulting in greater time spent in the hot work environment.

When performing physical work in hot conditions, sweat production can exceed water intake, leading to dehydration. Furthermore, research in some industrial environments reveals poor hydration practices. For example, Brake and Bates (2003) considered hydration among mine workers exposed to thermal stress while working extended shifts (12 hours). They report 60% of the miners commenced work dehydrated and their hydration status did not improve throughout the 10 to 12 hour shift.

Kenefick and Sawka (2007) identify some strategies for managing dehydration in the workplace, including:

1. Assessment of workers' hydration levels, although the selection of an appropriate assessment method is problematic. Methods of assessment, including isotopic dilution, bioelectrical impedance, and analysis of blood and/or plasma can be invasive, expensive, and hard to implement in a workplace. Less invasive and expensive methods of assessing hydration, such as urine specific gravity (USG) and urine colour have been used to identify risk of heat stress (Montazer et al., 2013). However, Kenefick and Sawka (2007) suggest measures of body weight and urine colour, used in combination with a subjective sense of thirst can provide a more meaningful assessment of hydration state than a single measure.

2. Educating workers in hydration practices and introducing a hydration program. Kenefick and Sawka (2007) suggest that informing workers who work in a hot environment about hydration assessment, signs and the dangers of dehydration, and strategies in maintaining hydration when working can reduce dehydration in the workplace. Kenefick and Sawka (2007) state that a hydration program should stress the importance of consuming meals. Advice about the consumption of hydrating foods can also be provided.

3. Ensuring that the work site has adequate access to cool and clean drinking water and bathroom facilities.

Kenefick and Sawka (2007) also argue that the development of guidelines for fluid intake under different conditions. They note that the American Conference of Governmental Industrial Hygienists and Occupational Safety & Health Administration both recommend that fluids be replaced by providing cool water or any cool liquid (except alcoholic beverages) to workers and that they be encouraged to drink small amounts frequently, such as one cup (250 ml) every 20 minutes. However, the amount of fluid required may vary depending on conditions.

Kenefick and Sawka (2007) also observe that the US military has developed specific work-pacing and fluid replacement guidelines that take into consideration the degree of work intensity and temperature (see Table 8.4)

Table 8.4: Fluid replacement and work/rest guidelines for warm weather training conditions used by the U.S. Army during training in hot weather

		Easy work		Moderate work		Hard work	
Heat category	WGBT index (F°)	Work/rest (mins)	Water intake (qrt/hour)	Work/rest (mins)	Water intake (qrt/hour)	Work/rest (mins)	Water intake (qrt/hour)
1	78-81.9°	NL	half	NL	Three quarters	40/20 mins	Three quarters
2 (green)	82-84.9°	NL	half	50/10 mins	Three quarters	30/30 mins	One
3 (yellow)	85-87.9°	NL	Three quarters	40/20 mins	Three quarters	30/30 mins	One
4 (red)	88-89.9°	NL	Three quarters	30/30 mins	Three quarters	20/40 mins	One
5 (black)	>90°	50/10 mins	One	20/40 mins	One	10/50 mins	One

Source: Adapted from Departments of the Army and Air Force (2003,p. 13).

When performing physical work, sweat output often exceeds water intake, producing a body water deficit or dehydration. Specific to the work place, dehydration can adversely affect worker productivity, safety, and morale. Legislative bodies in North America such as the Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) recommend replacing fluids frequently when exposed to heat stress, such as one cup (250 ml) every 20 minutes when working in warm environments. However, the majority of legislative guidelines provide vague guidance and none take into account the effects of work intensity, specific environments, or protective clothing. Improved occupational guidelines for fluid and electrolyte replacement during hot weather occupational activities should be developed to include recommendations for fluid consumption before, during, and after work.

Donoghue and Bates (2000) considered the impact of physical fitness on the risk of heat exhaustion in underground miners. They report that the odds ratios for heat exhaustion increased with BMI. For a BMI of 32.00-36.99, compared to a BMI of less than 27.00 the odds ratio was 3.63 (95% confidence interval, 1.42-9.36). Thus, Donoghue and Bates suggest that underground miners should be encouraged to stay fit and maintain a BMI of 27-27. Notwithstanding this advice, they also caution that the selection of workers on the basis of BMI is not an appropriate alternative control strategy to the provision of engineering control, such as effective ventilation and refrigeration systems for underground work.

The selection of personal protective equipment can also impact the risk of heat exposure. The wearing of bulky and thick protective clothing, which is often made out materials which are water-impermeable and block heat dissipation, can increase heat strain (Rowlinson et al., 2014). Protective clothing adds weight and increases the metabolic cost of undertaking a task. It can also require additional movement to compensate for other restrictions, such as reduction in field of vision or loss of manual dexterity (Nunneley, 1989). Clothing can also create a humid micro-environment and reduce the cooling effects of sweating (Nunneley, 1989). For example, Rowlinson et al. (2014) recorded a temperature of 57 C° inside a safety helmet when the outside temperature was 33 C°.

Lucas et al. (2014) argue that it is important that the properties and performance of clothing (in particular their impacts on the body's thermoregulation) are well understood and that high-performance clothing is used in occupational environments in which workers will experience high thermal loads. Chan et al. (2016) developed and evaluated an anti-heat stress work 'uniform' that has become standard industry requirement in the construction industry of Hong Kong.

Commercially available cooling vests have also been found to be effective in reducing thermal strain when working using normal clothing/workwear, as well as heavy protective clothing (Kenny et al. 2011). Cooling bandanas, neck shades and helmet inserts are also commercially available.

Finally, individual workers should be provided with information and training about the risks and symptoms of heat stress so that these symptoms can be recognised in themselves or others (Rowlinson et al., 2014, Safe Work Australia, 2013a). Rowlinson et al. (2014) advocate the use of a personal heat risk assessment checklists which includes personal health factors, such as age, gender, physical fitness, hydration state, medical factors, alcohol consumption, smoking habits, etc. because these factors can affect workers' vulnerability to heat stress.

8.5 Control measures for vibration

Construction workers are frequently exposed to vibration at work. As well as reducing their performance, vibration also damages their health. Depending upon the nature of their work, construction workers can be exposed to either two types of vibration hazard. The first is whole-body vibration (WBV), which is the vibration transmitted into the body resulting from operating machinery such as rollers, dump trucks or excavators. The second is hand-arm vibration (HAV), which is transmitted into the hands of operatives, with prolonged or repeated exposure posing a risk to the workers. Workers can suffer as a result of both continuous vibration and of sudden impulsive shock (Edwards & Holt, 2006). There are a number of studies in support of this, for example, a recent study by Kamalakar and Mitra (2018) proposed a five Degree-of-Freedom (DOF) human hand-arm system model to analyse HAV in terms of acceleration responses. The study analysed one of the possible protective ways to reduce hand-transmitted vibration by using the anti-vibration isolators to the machine handle. In another study, Lundstrom et al. (1995) analysed the workers who were exposed to vibration on a regular basis at an engineering industry and found a significant association between the cumulative vibration dose and the deterioration of fingertip vibration protection threshold (VPT).

Hand-Arm Vibration (HAV)

This type of vibration can be transmitted to the hands and arms of operators from vibrating tools and, depending on the type and place of work, segmental vibration can be transmitted to one arm only or to both arms simultaneously. These vibrations may be transmitted through the hand and arm to the shoulders (Mirbod et al., 1997). Construction workers experience HAV to varying extents (both in terms of magnitude and exposure duration) and as such it is not easy to evaluate the exact degree of effect (in regards to its intensity, frequency, or duration of vibration exposure) of vibration. This is because other factors such as ergonomic (static load, power grip, etc.) and individual characteristics play a role in the final outcome after exposure (Vihlborg et al., 2017). HAV is defined as a “vibration transmitted to the hand and arm when using hand-held power tools, and hand-guided machinery and while holding materials being processed by machines. HAV is commonly experienced by people who use jack-hammers, chainsaws, grinders, drills, riveters and impact wrenches” (Safe Work Australia, 2016b). Exposure to HAV can result in damage to the hand and arm including, but not limited to:

- disrupted circulation
- damage to nerves resulting in tingling and numbness in the hand
- damage to tendons, muscles, bones and joints, and
- specific disorders e.g. carpal tunnel syndrome and vibration white finger.

Given this, the European Union Physical Agents Directive 2002/44/EC established minimum H&S requirements regarding the exposure of workers to the risks arising from physical agents, including HAV (Griffin, 2004). However, despite on-going research more needs to be learnt on exposure-response relationships for HAVs (Hewitt & Mason, 2015).

To address this problem, new technologies have been recently introduced. This includes wearable sensors, which can measure HAV. However, use of this technology in the construction industry is still not easy due to the dynamic nature of the construction site. However, the application of new technologies can reduce the extent to which workers are exposed to HAV. One example is replacing the use of a jackhammer for breaking concrete piles with alternative hydraulic or chemical breaking systems (HSE, 2002).

However, the use of these technologies needs to be considered during the planning and design stages of construction projects. Failure to identify opportunities to reduce exposure to occupational health hazards at early project life cycle stages (when important decisions are being made about technologies and the design of work processes) has been identified as a barrier to the adoption of technology-based risk control methods. These technologies provide important opportunities to continuously measure HAV in an objective way and to use this information to inform the decisions of tools and equipment, as well as task and work process design (Anderson and Buckingham, 2017).

Exposure to HAVs should be reduced so far as is reasonably practicable. This can be done by designing workstations in a way that minimise loads on workers' hands and arms (HSE, 2011). In addition, and where appropriate, work should be automated or mechanised to eliminate vibration (HSE, 2011). It is also recommended to use alternative work methods, which reduce vibration exposure (HSE, 2011). As an example, a breaker attachment on an excavating machine could be used to break concrete instead of using a hand-held breaker. Another example is using a diamond-hole cutting drill bit with a rotary action instead of a tungsten-tipped hole bit (which, as a result may reduce the exposure time) (HSE, 2011). In addition, whenever possible, alternative equipment and consumables should be used to reduce the duration of the vibration. This may include machine-mounted hydraulic breakers, hydraulic crushers, hydraulic bursters or hydro-demolition, instead of using hand-held hammers and / or breakers (HSE, 2011, Shanks et al. 2013). Recent research conducted in rail infrastructure construction projects in Melbourne also revealed high levels of HAV associated with manual hand-held shotcreting. As a result, it is strongly recommended to use mechanised shotcreting equipment to reduce the risk of HAVs (see Figure 17 below).

Manual hand-held shotcreting

Mechanised shotcreting

Figure 17: Images of manual and mechanised shotcreting

A summary of different vibration eliminating or reducing devices is presented in Table 8.5 below:

Table 8.5: Overview of different vibration eliminating or reducing devices

Vibration reducing device	Application
Comfort grips	A rubber and wood device designed to fit on a pistol grip air powered stone chisel that can be single handed or double handed
Anti-vibration side handle	Use on an angle grinder instead of the 'standard' side handle
Rear handle bushing	Separates rear (trigger) handle of an angle grinder from the rest of the machine body
Grinding wheel balancers	Pedestal grinders
Elephant trunk suspension system	Takes the mass of the machine allowing for easier use and lighter grip
Drilling rigs	Reduces or eliminates the direct contact between the user and an electric impact drill by jig mounting the drill at the appropriate working height. This also has an ergonomic advantage of allowing the operator an improved working posture.
Saw clamping system	Eliminates the need for the operator to hold a metal cutting reciprocating saw by clamping the saw to the work piece and using gravity to allow the saw to make progress.
Sleeves / resilient coatings	Can be applied to part of a machine that is gripped by the user, such as chisel sleeves
Consumables	Saw blades, grinding discs, ceramic abrasives, steels for road breakers or chisels – some specifically claim to reduce vibration
Tensioners / spring balances	Used with heavy tools such as nail guns, sand rammers and angle grinders. Bears the load of the tool allowing the user a lighter grip. Also allows mass to be added to a system to damp vibration.

Source: Adapted from Shanks et al. (2013)

Administrative control measures for HAV risk include informing workers about the risks of vibration and how equipment can be used to minimise vibration (HSE, 2012b).

Training should also be provided for staff with responsibility for purchasing equipment so that purchasing decisions effectively reduce the exposure to HAV.

Where possible, hand held power tools and equipment must be checked to determine the extent to which they pose a risk of HAV before making a purchasing decision (HSE, 2011). In addition, the amount of time using tools that produce high levels of HAV should be kept to a minimum. Work should be planned to involve multiple short periods of use, rather than extended periods of continual use. Where machines or tools require a continual use, a worker rotation scheme should be implemented (HSE, 2011). Regular breaks should be arranged for workers who are exposed to HAV. Workers should also be encouraged to exercise their fingers at regular intervals (HSE, 2011). It is also recommended to check results of health surveillance regularly and to ask workers and supervisors regularly if there are any HAV problems with tools, equipment or machines being used in a workplace or process (HSE, 2011). Feedback provided by workers should be used to inform decisions to replace high-risk equipment as well as future purchasing decisions. It is important that control measures are regularly checked. The results should be discussed with health service provider whether the controls appear to be effective or need to be changed (HSE, 2011).

Equipment should be routinely checked to ensure it is not damaged, is well maintained and is replaced regularly (HSE, 2011). All devices and equipment should be maintained regularly to prevent an increase of vibration (HSE, 2011). Workers should be provided with clothing, which encourages good blood circulation, which is important in the prevention of vibration white finger.

Whole-body vibration (WBV)

Whole-body vibration (WBV) is defined as vibration occurring when a greater part of the body weight is supported on a vibrating surface (Futatsuka et al., 1998). Generally, WBV is caused by vibration transmitted through the seat or the feet by workplace machines and vehicles, which can produce systemic effects on the entire body (Kittusamy & Buchholz, 2004). Working posture is influenced by many factors including workstation layout, location and orientation of work, individual work methods, and the workers' anthropometric characteristics (Hsiao & Keyserling, 1990). In addition, an initial review of existing literature suggests the need to comparatively evaluate cognitive performance in situations of exposure and non-exposure to WBV (Lin et al., 2008; Messina et al., 2009; Mani et al., 2010). Although vibrational motion can be generated in all three directions, latitudinal (X), longitudinal (Y) and vertical (Z), traditionally only the vertical (Z) component is addressed during environmental studies. That is because this component contains more energy and its motion is less constrained than in either the X or Y directions. However, when assessing vibration in vehicles, the most severe vibration component can come from any direction (Thalheimer, 1996). The main health effect from whole-body vibration is damage to the lower spine area (HSE, 2011). However, the reported effects on the spinal system are only part of the problem with whole body vibration as other parts of the body are affected depending on the work environment, dominant frequencies of the vibration and posture during exposure (Groothoff, 2007).

In Australia, WBV exposure is one of the most overlooked health hazards with a very low level of risk assessment (HASPA, 2012). In the construction industry, workers on construction machineries are vulnerable to whole-body vibration (Smith and Leggat, 2005). So far, limited studies have been carried out to evaluate the WBV exposure experienced by construction workers (Zhao & Schindler, 2014). In recent years, Zhao & Schindler (2014) analysed the WBV exposure of operators of compact wheel loaders according to ISO 2631-1:1997.

Kubo et al. (2001) suggested that the responses of the human body when exposed to vibration could be explained by three sets of reactions:

- the reaction expressed by the physical transmission of vibrations from one body part to another
- the physiological reaction that is manifested by changes in blood pressure, heart rate, etc., and
- the psychological reaction as a result of the vibration (which includes physical symptoms such as tiredness and yawning, mental symptoms such as distracted attention and nervous symptoms such as headache and dizziness).

The most widely known WBV guideline is the International Standards Organisation's ISO 2631-1:1997 and ISO 2631-5:2004 "Guide for the Evaluation of Human Exposure to Whole-Body Vibration". In Australia, the current Australian standard for assessment of WBV is AS 2670.1 "Evaluation of human exposure to whole-body vibration - general requirement (SA, 2001)".

Having noted this, control measures of WBV have both similarities and differences to HAV control measures; the main difference being that in WBV, machinery is involved. Additionally, and as previously mentioned, the psychosocial aspects are more critical in WBV. HSE (2012) recommends that in order to eliminate the risks, we can consider replacing the manned with unmanned machines (for example using remote controlled conveyors). In addition, choice of vehicles can be an important means of reducing exposure to vibration since each vehicle varies in vibration emissions, visibility (which indirectly adds to the vibration hazard), choice of seat and tyres. In administrative controls, it is important to reduce the duration of exposure as reasonably practicable (by means of shift rotation). Training is also necessary with Safe Work Australia (2016b) recommending that training must cover information about the sources of WBV and how the vibration can be minimised (e.g. with proper seat adjustment), as well as how to recognise and report symptoms. Moreover, similar to HAV, the amount of time using tools that produce high levels of HAV should be kept to an absolute minimum. Work should be planned to involve multiple short periods of use, rather than extended periods of continual use (HSE, 2011). Engineering controls, besides the above-mentioned points for HAV, should include the layout of workplace sites being designed in a way to reduce the need to transport materials, and so reduce the WBV exposure of drivers/operators, whilst and PPE must protect employees from cold and damp (since exposure to the cold may accelerate the onset or worsen the severity of back pain which is a consequence of WBV). Thus, it is good practice to ensure that those working in the cold are provided with warm, and (if necessary) waterproof clothing.

Control strategy (Risk assessment, control measures and monitoring)

The OSHA factsheet for prevention of vibration risk in construction, notes that before developing a control strategy, a complete risk identification and assessment must be done. But it notes that when assessing risk related to a particular solution, the established risk level is often based on background knowledge (including assumptions, phenomenological understanding, data and expert statements) and the strength of this knowledge could be weak especially when addressing long-term risks (Berner & Flage, 2017). Furthermore, Hulshof et al. (2006) propose that in addition to the occupational factors, non-occupational and individual risk factors also play a role in the development and duration of vibration-related health problems.

In addition, Boden et al. (2016) report that as both the structure and organisation of work is continually changing (both in cyclical and unidirectional ways), it is important that experts continually re-evaluate strategies based upon existing and new risks, changing work organisation, evolving technologies, social relationships and shifts in the industrial mix. This issue is particularly important in the site environment in the construction industry. Having said this, Hulshof et al. (2006) recommends an approach, which systematically analyses the exposure by five following steps: recognition, criteria, measurement, evaluation and control. Safe Work Australia (2016b) recommends when to control for the risk, source, path and point of entry. In this regard, factors such as plant characteristics, work environment, work organisation and individual characteristics must all be considered (Safe Work Australia, 2016b).

The evaluation and assessment of risks arising from exposure to both HAV and WBV can be complicated. To simplify this, McPhee et al. (2009) proposed that the risk management for vibration hazards must be done in a cycle, in which risk identification and assessment are the first steps (Figure 18 below).

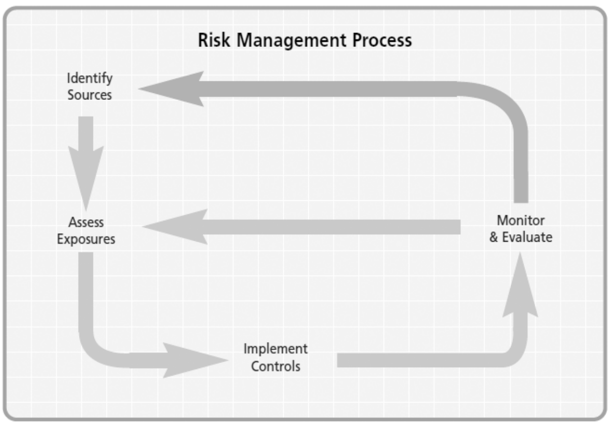

Figure 18: Risk management process

Source: McPhee et al. (2009, p. 10.)

Praščević & Mihajlov (2014*)* propose that when assessing the risk from HAV in the workplace, the following steps must be taken as part of the risk assessment process:

- identification of vibration in the workplace
- determination of daily exposure duration
- determination of the magnitude of vibration
- calculation of the daily vibration exposure, and
- comparison with reference limits

Monitoring

The management of vibration exposure is an ongoing process in the evaluation of the control systems. In this regard, proposed HAV control measures must be periodically reviewed to ensure their effectiveness. The following three steps can do this:

- checking the results of health surveillance
- using safety leading and lagging indicators, and
- using a two-way feedback system (which includes manager, supervisor and workers).

8.6 Control measures for ultraviolet radiation (UVR)

Gies & Wright (2003) measured the ultraviolet radiation exposure of workers in the construction and building industry in Queensland by using UVR-sensitive polysulphone film badges. The results show that some workers were exposed to extreme levels of UVR, especially in cases where they did not use appropriate and adequate sun protection.

Stock et al. (2011) highlight that labourers in construction trades have an increased incidence of work-related ill-health such as skin neoplasia.

Solar UVR has three wavelengths: UVA, UVB and UVC. UVA and UVB are carcinogens which means that they are able to cause cancer (Cancer Council Australia, 2017b). The risk of skin cancer is linked to UV radiation overexposure (see, also Gawkrodger 2004; Safe Work Australia, 2013b). Overexposure damages skin cells and increases the risk of developing cancer. In addition to that, solar UVR is also attributed to cancer of the eye, pterygium[5] and cataracts[6] (Cancer Council; Australia, 2017). Excessive exposure to UV radiation over a long period of time increases the risk of developing skin cancer (Queensland Government, 2010).

The exposure limit for solar UVR in Australia on the skin or eye is 30 Jm^{-2} during an eight-hour working day (Australian Radiation Protection and Nuclear Safety Agency, 2006). Limits recommended by the American Conference of Governmental Industrial Hygienists contain 1 mill watt/ cm^2 for intervals greater than 1000 seconds for the eye (for the UV-A or near ultraviolet spectral region). If the exposure time is below 1000 seconds, the total energy should not be more than 1.0 J/cm^2. Additional exposure limits apply to the amount of UV light exposure to the skin and the eyes (CCOHS, 2018). These limits are for occupational exposure to ultraviolet radiation for artificial sources in the workplace but it also provides guidance on minimising sun UVR (ARPNSA, 2006).

Safe Work Australia recommends that work should be carried out indoors if the ultraviolet radiation (UVR) exposure is from a solar source (Safe Work Australia, 2013b). However, when working in the construction industry, working indoors is often not possible.

Wherever possible, work should be moved to existing shade at the worksite, such as shade from trees or buildings (Safe Work Australia, 2013b). If possible, reflective surfaces should be avoided or replaced to reduce reflective UVR (Cancer Council; Australia, 2017). Grass or soil for example, reflects less than 10 per cent of UV radiation (WHO, 2018).

Engineering control measures for UVR can include the installation of shade structures over (outdoor) work sites and over rest break areas (Queensland Government, 2010, Safe Work Australia, 2013b). Where permanent structures are not feasible, for example in the case of constantly changing construction worksite conditions, portable sunshades

5 Pterygium a growth on the white of the eye (Cancer Council Australia, 2017b).

6 Cataracts is a clouding on the lens of the eye (Cancer Council Australia, 2017b).

may be a quick and cheap solution for the protection of small numbers of people (Safe Work Australia, 2013b).

If possible, a combination of different shade protection control measures should be considered to ensure the best protection (Safe Work Australia, 2013b). However, the effectiveness of shade control measures is dependent upon the materials, design and construction of protective shading.

Workers inside of vehicles could be protected from UVR exposure by an application of (tinted) films to the side windows of their vehicles to reduce the amount of UVR exposure coming through the windows. A limitation of this control measure is that level of protection varies between different products whilst it is also necessary to keep windows closed to ensure the effectiveness of the films and tints (Safe Work Australia, 2013b).

If the UVR exposure is from a non-solar source, such as from welding, engineering controls, such as door interlocking power supplies, UVR blocking filters or opaque barriers should be considered (WHO, 2003).

Administrative controls for UVR risks include the scheduling of outdoor work in the early morning and late afternoon when the level of ultraviolet radiation is lower (Safe Work Australia, 2013). If possible, the exposure limit should be reduced by planning indoor or shaded work tasks when levels of UV are strongest between 11 am and 3 pm (Safe Work Australia, 2013, Queensland Government, 2010). Other possibilities to limit the exposure time include:

- the rotation of workers who are exposed to outdoor exposure to UVR (Safe Work Australia, 2013b, Queensland Government, 2010) or
- increasing the number of workers involved in a particular task to reduce individual workers' exposure time (Queensland Government, 2010).

If possible a variation of tasks to reduce exposure times should be considered (Queensland Government, 2010). Work practices and activities can also be reorganised to reduce exposure, for example the length and frequency of rest breaks may be increased (Queensland Government, 2010).

To prevent workers from solar UVR workers should be informed and trained to work safely in the sun. Target groups should include also health and safety personnel, supervisors, management and safety officers. This training should be provided for all workers working outside and also new workers as part of their induction (Cancer Council Australia, 2007, Safe Work Australia, 2013b). Workers should also be informed about the harmful effects of UVR exposure and who is at risk on the worksite (Queensland Government, 2010, Safe Work Australia, 2013b). Daily information of the UVR Index should be provided or workers encouraged to use a UVR alert (e.g., SunSmart UVR alert) on their smartphones (Cancer Council Australia, 2017b, Safe Work Australia, 2013b).

It is also important to provide education to workers about how to examine their skin effectively (Safe Work Australia, 2013b) and to provide health surveillance, including regular skin and eye checks for exposed workers (Queensland Government, 2010).

The Cancer Council Australia (2017b) recommends an annual assessment of the effects of UVR.

The use of personal protective equipment is a critical protective measure for outdoor construction workers. Workers should be provided with broad-brimmed sun protective hats, which cover their neck, ears, head and face. A brim should cover at least 7.5 cm and 6 cm for bucket hats. Legionnaire hats provide also a good protection from UVR (Cancer Council Australia, 2017b).

To ensure protection against solar UVR protective work clothing should be long-sleeved and tightly woven shirts with collars. Workers should wear long trousers. However, colour, condition and closeness can affect the ability to protect from UVR exposure. Materials such as cotton, linen or polyester can protect against 95 per cent of UVR (Cancer Council Australia, 2017b, Safe Work Australia, 2013b). Employees should be involved in the process of designing or selecting suitable protective equipment that protects against UVR (Cancer Council Australia, 2017b).

A UPF rating indicates how effective fabrics block out UVR. 'Good Protection' is provided by UPF ratings between 15 and 20. A 'Very Good Protection' is provided by ratings of 25, 30 and 35. 'Excellent Protection' is provide by of 40, 45, 50 and 50+. The UPF rating is influenced by the following factors such as:

- colour (darker colours are usually better)
- composition of the yarns
- condition (clothes which are worn out or have faded parts may provide a lower level of protection)
- tightness of the weave or knit (tight clothing provides better protection)
- stretch (stretching reduces the level of protection)
- finishing (such as a treatment with UVR absorbing chemicals), and
- moisture (the protection might be lower when fabrics are wet) (ARPANSA, 2018).

Training should also include a correct application and usage of personal protective equipment. Outdoor workers should be trained how to apply sunscreen effectively. The sun protection factor of sunscreen should be at least SPF 30 or higher for the skin, SPF 15 or higher for lip-balms. Sunscreen should be water resistant (Cancer Council Australia, 2017b, Safe Work Australia, 2013, Queensland Government, 2010). However, sunscreen is only effective if it is applied correctly on dry and clean skin and applied 20 minutes before working outside. To remain effective, sunscreen should be reapplied at least every two hours and even more often in case the skin was washed or rubbed excessively. A minimum of one teaspoon per arm / leg e.g., half of a teaspoon for the face including neck and ears is recommended as the right amount of sunscreen to apply (Safe Work Australia, 2013b). Inappropriate storing can reduce the effectiveness of sunscreen, which should be stored at a temperature no hotter than 30 degree Celsius (Safe Work Australia, 2013b).

Wearable personalised devices have also been developed that help people to understand UVR exposure and facilitate sun protection behaviour. For example, UV SPOTs have been trialled. UV SPOTs are applied to the skin and change colour when sunscreen (applied over the spot) is no longer providing protection. Wearable UVR trackers also monitor exposure and connect to digital mobile devices to provide readings and warnings when dangerous levels of UVR exposure are reached (Gizmodo, 2017).

Finally, fabric patches in protective clothing and workwear can indicate (by changing colour) when the protective performance of clothing has been degraded, enabling workers and supervisors to know when items of protective clothing need to be replaced (Pościk, 2013).

Exposure to solar UVR can contribute to acute eye damage, such as age-related macular degeneration which can cause blindness (Safe Work Australia, 2013b). To prevent workers from solar UVR workers should also be provided with sunglasses. Sunglasses can provide a good protection depending on their design and the qualities of the lens. In Australia, sunglasses have to meet the requirements of AS1067 / Australian Standards (Queensland Government, 2010, Safe Work Australia, 2013b). Polarised lenses will not necessarily block UVR, whereas sunglasses with an eye protection factor of 9 or 10 let almost no solar UVR pass through. Close-fitting, wrap around style sunglasses offer the best protection. Workers who need extra protection from glare or falling objects should wear specialist safety sunglasses (meeting AS/NZS 1337.1:2010). Although safety sunglasses already provide solar UVR protection they require tinting to use them outdoors (Safe Work Australia, 2013b).

Managers, foremen and supervisors should be encouraged to act as positive role models, by adopting sun smart work practices (Safe Work Australia, 2013b). Sun protection practices should also be implemented during work-related events and the workers should be encouraged to adopt sun smart practices in their non-work leisure activities (Safe Work Australia, 2013b).

If UVR exposure is from a non-solar source, such as from welding, administrative control measures include warning signs. Moreover, workers should keep a safe distance from the UVR source and strict time limits should be imposed on work while emitting machinery is switched on (WHO, 2003).

Finally, as will all control measures, the effectiveness of UVR controls should be monitored and reviewed regularly (Cancer Council Australia, 2007, Queensland Government, 2010).

8.7 Control measures for psychosocial hazards

Sources of psychosocial risk in construction

Psychosocial hazards and work-related stress are prevalent in the construction industry (Bowen et al. 2014). Project-based construction work is characterised by long hours of work, job insecurity, perceived conflict between work and family life and low levels of autonomy and control (Boschman et al., 2013, Lohmann-Haislah, 2012; Haynes & Love, 2004). All of these work characteristics have been linked to diminished health (Hannertz et al., 2005; Van der Hulst 2003; Turner and Lingard, 2016). Research shows that construction workers are a high risk group for psychological distress and mental illness (Abbe et al., 2011). Job burnout has been reported to be high in managerial and professional construction workers (Lingard & Francis, 2005; Lingard et al. 2006). High levels of burnout leading to early retirement have also been reported in manual, non-managerial workers (Oude Hengel et al., 2012). The incidence of mental distress among construction workers is reported to be twice the level of the general male population (Borsting Jacobsen et al., 2013). Most disturbingly, Meltzer et al. (2008) report a high rate of suicide among construction workers compared to other occupations. In Australia, construction workers are six times more likely to die by suicide than through a workplace accident; and construction apprentices are two and a half times more likely to suicide than other young men their age (Mates in Construction, 2016).

Construction workers are a high risk group for musculoskeletal disorders (Petersen and Zwerling, 1998). Traditional approaches to health have viewed the mind and body as functioning independently. This view does not adequately explain illness, which refers to a person's subjective appraisal of the symptoms of disease (Gatchel et al. 2007). There is a growing understanding that psychological and social processes interact with biological factors in shaping mental and physical health. Consistent with this view, there is a substantial body of research evidence demonstrating a link between the experience of workplace psychosocial stressors (for example low levels of social support and job satisfaction and high perceived job stress) and musculoskeletal problems (Hoogendoorn et al., 2000; Bongers et al., 2002).

Borsting Jacobsen et al. (2013) report that mental distress in construction workers is strongly significantly associated with the experience of lower back pain, having two or more pain sites and the experience of injury. Stattin and Järvholm (2005) similarly report that physical, ergonomic and psychosocial work demands all increase the odds ratio of construction workers seeking a disability pension. Importantly, the effects of physical and ergonomic risk factors are exacerbated when workers have low job control or autonomy. Similarly, a Danish study reveals psychosocial work factors predict early retirement of workers in physically heavy occupations, even after controlling for disease (Lund et al., 2001).

The pathway between psychosocial risk factors and chronic pain is not entirely clear but some possible explanations for the links have been suggested as follows:

- demanding work directly impacts the speed and acceleration of movement, applied force and posture, contributing to musculoskeletal injury

- demanding work triggers sustained stress responses and may cause physiological changes contributing to musculoskeletal injury
- stress responses may lead workers to appraise work situations and musculoskeletal symptoms differently, and/or
- stress responses may influence the transition from acute to chronic musculoskeletal pain (Bongers et al. 2002).

This research points to the potential benefits of providing an integrated preventive approach focused on addressing both physical and psychosocial risk factors inherent in construction work (MacDonald et al. 2001)

Risk assessment approaches

Psychosocial risk factors need to be properly assessed and appropriate risk control measures selected and implemented to prevent ill-health.

In Germany, for example, companies have to conduct a risk assessment which includes physical and also psychological hazards. Areas that are the focus of psychological risk assessment are (Hahnzog, 2015):

- job content (e.g. job control, job variety and responsibility)
- work organisation (e.g. working hours, opportunities to communicate)
- social relationships (e.g. social support from the supervisor, social support from colleagues)
- work environment (e.g. physical hazards which have an impact on the psychological wellbeing), and
- new forms of work (e.g. atypical employment).

Further, this risk assessment should not be conducted as isolated one-off event. Instead, it should be understood as ongoing process to optimise workers' health and safety over time (Hahnzog, 2015). The Irish Health and Safety Authority also recommends a free-online risk assessment 'WorkPositive' which is available at https://www.workpositive.ie/.

Control measures for psychosocial risk

A report conducted by the European Agency for Safety and Health at Work (2012) considered the applicability of the traditional risk management paradigm adopted for physical health and safety hazards to psychosocial risks. The applicability of this approach to the management of psychosocial risks has been questioned due to fundamental differences between the nature of psychosocial risks and physical risks, as follows:

- physical hazards are usually context-specific (i.e., specific to a work area or work process), while psychosocial hazards can be found in any department and hierarchical level of an organisations (e.g. low social support, work pace)
- the risk of harm for an individual from a physical hazard can usually be precisely defined and exposure levels specified. Such definition is far more difficult for psychosocial risks (e.g.it is very difficult to determine at what level a lack of social support or job security will be harmful), and

- physical hazards always have the potential to cause harm but the potential effects of psychosocial hazards can sometimes be positive (e.g. career advancement).

Workplace interventions designed to address psychosocial risks can be implemented at three stages, which do not directly correspond with the hierarchy of control but bear some similarities to it (See Figure 19). These stages include:

- primary interventions – which are proactive and aim to prevent the emergence of harmful phenomena
- secondary interventions – which aim to reverse, reduce or slow the progression of ill-health or increase individual resources, and
- tertiary interventions – which are rehabilitative in nature and aim to reduce negative impacts and heal damage (Murphy & Sauter, 2004).

Like technological risk controls in the traditional WHS risk management paradigm, primary interventions for psychosocial risk are designed to change the work environment and remove psychosocial hazards, therefore reducing the potential for psychological injury. These measures deal with issues of work design, organisations and management that are identified to be particular problems in an employment context (Nielsen et al., 2010). As previously discussed, job insecurity, work-family conflict, long and non-standard hours, and time pressures have all been identified as risk factors in construction. Primary prevention measures target a group of workers, rather than individuals and involve redesigning work practices, for example reviewing job scheduling or changing work time arrangements.

Primary prevention measures implemented in the Australian construction industry include the adoption of alternative work-scheduling arrangements, including compressed work weeks to enable a five day working week (Lingard et al. 2008).

Secondary level interventions for psychosocial target groups identified as being at risk of exposure and aim to improve their perception and management of psychosocial risks so that emergent cases of work stress can be promptly identified and managed. Secondary level interventions seek to give workers the ability to identify and manage stressful conditions through awareness training and the provision of supports and coping resources. Hesselink and Jain (2014) state that secondary prevention measures are not a substitute for primary prevention measures.

Compared with primary and secondary prevention measures, tertiary prevention measures for psychosocial risk can be regarded as reactive. They aim to reduce the effects of exposure to psychosocial hazards after it has occurred by managing or treating the symptoms of psychological injury or illness, for example strain, burnout, or depression. Examples of tertiary prevention include therapy, counselling, return-to-work practices and occupational rehabilitation. Employee assistance programs are an example of organisationally-provided tertiary prevention programs.

	Primary	Secondary	Tertiary
Legislative- policy	Legislation to limit hours of work	Worker compensation	
Employer/ organisation	Work-family programmes	Return to work programmes	Company provided long-term disability
Job/ Task	Job/task design, Job enrichment, Job rotation	Provision of light duty jobs	
Individual/ job interface	Health promotion programmes	Stress management programmes	Employee assistance programmes Disease management programme

Figure 19: Intervention levels for psychosocial risks

Source: Hesselink & Jain (2014)

In-keeping with legislative responsibilities to prevent work-related injury and illness, the best means of controlling psychosocial risks in the workplace are primary prevention measures. These can include: changing task characteristics, work conditions or addressing issues of role clarification and social relations in the workplace. Such changes can take time to implement and can require focus on re-training and change management, which workers can also find stressful. Semmer (2006) also cautions that the effects of primary prevention interventions to reduce psychosocial risks will be less predictable than secondary prevention measures because primary prevention measures target aspects of complex social systems in which change can be difficult to manage or maintain.

However, a large number of documented workplace interventions for psychosocial risk factors can be classified as secondary interventions, for example the implementation of guidelines and policies establishing rules about how to respond to bullying allegations and conflicts in the workplace, as well as aggression or violence (Health & Safety Authority and National Treasury Management Agency, 2017).

The focus of many secondary prevention measures is also on training to raise awareness and equip workers with knowledge and skills to respond to issues such as work-related stress, harassment, bullying etc. Hesselink and Jain (2014) note that, although these approaches are conceptualised as individual level interventions, they often reflect the fact that work is performed in teams and address issues such as interpersonal relationships and conflict management in the workplace.

Some secondary prevention measures provide coping resources, for example time management, stress management or mindfulness training programs. For example, meta-analyses conducted by Grossman et al. (2004) and Keng et al. (2011) suggest that mindfulness training can have positive effects on individual workers' well-being and that mindfulness-based stressed reduction training can potentially individuals to cope with different problems.

Digital/mobile technologies have also now been deployed to deliver mindfulness awareness and support through applications such as ‘Smiling mind’ and ‘Mindfulness daily’ (Mani et al., 2015).

Similar applications have been developed to support and help people with mental health conditions. These applications can be combined with other data collection processes, such as monitoring of sleep.

Donker et al. (2013) analysed the effectiveness of digital/mobile mental health applications and found that they can produce significant improvements. However, Donker et al. (2013) caution that many applications have not been scientifically evaluated and more work is needed to provide a robust evidence-based and to identify factors affecting their use and effectiveness in certain circumstances (see, also Cho et al., 2014).

Stress management interventions have also been classified according to the level in the organisation that the intervention targets, i.e.: the individual employee, the organisation or the organisation-individual interface. Examples are provided in Table 8.6.

Table 8.6: Levels of stress management intervention

Level	Example
Individual	Relaxation Meditation Biofeedback Cognitive-behavioural therapy Exercise Time management Employee assistance programs
Individual/organisational	Co-worker support groups Person environment fit Role issues Participation and autonomy
Organisational	Selection and placement Training and education programs Physical and environmental characteristics Communication Job redesign/restructuring

(Source: Giga et al. 2003)

Social support

Several studies highlight the importance of social support in mitigating psychosocial risks in a workplace (Kim et al. 2008; Pluut et al., 2018). Workers who perceive a lot of social support report fewer health complaints (Lohmann-Haislah, 2012). Moreover, previous studies found connections between social support and better health status in case of coronary heart diseases or depression (Holahan et al. 1997, Kim et al, 2008).

In the Australian construction context, Lingard and Francis (2006) report that perceived organisational support and supervisor support provided a protective buffer against the effects of work-family conflict. That is, under conditions of high organisational support and supervisor support, construction workers experiencing work-family conflict were less likely to develop burnout compared to workers experiencing low levels of social support. Importantly, this protective effect was observed when supervisors provided practical support. No such effect was found for supervisors who provided emotional support but who were not able to make practical adjustments to help workers to manage the work-family interface.

Rump et al. (2016) argue that managers are often ill-equipped to support workers to manage psychosocial risk factors (Rump et al., 2016).

A health promoting leadership style is characterised as one that is worker-focused, supportive of worker co-determination and participation in work design (Rump et al., 2016). Research suggests this leadership style provides health benefits and is learnable, suggesting that supervisor training in the construction industry could be beneficial (Rigotti et al., 2014). Supervisors of culturally diverse work groups should also be informed about the importance of social support for workers from different cultural backgrounds (Hoppe, 2011).

Starting points could be interactive presentations and workshops which provide an overview about occupational health in general and stress and leadership in particular (Rigotti et al., 2014). Information about social support and its importance should also be shared between workers with the aim to increase the social support between workers.

Furthermore, implementation of a health circles may be considered. Health circles are groups which analyse existing problems and develop recommendations how to solve these problems and became more and more popular in Europe (Semmer & Zapf, 2004). A characteristic of health circles is that all workers are welcome to participate (Semmer & Zapf, 2004).

Part 9: Appendix B

Diesel engine exhaust emissions – risk control hierarchy

Elimination	Replace diesel powered plants with electrically driven, propan, compressed natural gas or petrol fuelled vehicles
Substitution	Use of lower diesel emission engines Use of cleaner fuels (e.g. low sulphur diesel) Use more fuel-efficient engines (HSE, 2012a, Safe Work Australia, 2015b, OSHA, 2013)
Engineering	Installation of engine exhaust filters (for example, a filter system which consists of a porous ceramic filter, one diverter valve plus an electronic control module; installation of a two-stage diesel emission control system (Karpinski, 2015) Installation of a local tailpipe exhaust ventilation which attaches a hose to the tailpipe and connects the tailpipe to a fan (Karpinski, 2015; HSE, 2012a, OSHA, 2013) Other ventilation techniques such as dilution ventilations (Karpinski, 2015) or local extraction ventilation (HSE, 2012a) Combination of local extraction ventilation with other ventilation such as the tailpipe exhaust ventilation (HSE, 2012a). Use of other exhaust ventilation, such as exhaust gas recirculation, catalytic converters or selective non-catalytic reduction (HSE, 2012a, Karpinski, 2015) Use of diesel emissions ‘after treatment’ systems (HSE, 2012a, BAuA, 2009) Fitting exhaust gas recirculation systems (HSE, 2012a, Karpinski, 2015) Use enclosed cabins in vehicles with filtered air (Hedges, Djukic, & Irving, 2007, Organiscak, Cecala, & Noll, 2013) Provide fresh air by using controls like a canopy air curtain to cover roof bolters operators (Listak & Beck, 2012) and enclosed cabin filtration systems (Organiscak, Cecala, & Noll, 2013) Separation of areas in which diesel engines are operating (Safe Work Australia, 2015b, BAuA, 2009)
Administrative	Use processes or systems of work which reduce the generation of DEEEs (HSE 2012a) Reduce the number of employees directly exposed and their period of exposure, for example through job rotation (HSE, 2012a, OSHA, 2013) or work schedules (Safe Work Australia, 2015b)

	Prohibit / restrict unnecessary lugging or idling of engines (OSHA, 2013) Restricting the total engine horsepower and number of diesel-powered equipment in defined areas (OSHA, 2013) Allocate areas without any diesel engine operation and personnel travel (OSHA, 2013) Set up speed limits and put one way traffic routes into place to reduce the level of traffic (OSHA, 2013) Restrict the number of vehicles operating according to the capacity of the ventilation system (OSHA, 2013) Perform regular maintenance of all diesel-powered machines and equipment (BAuA, 2009, HSE, 2012a, Karpinski, 2015, OSHA, 2013). Perform annual training for the workers Perform a routine cleaning or replacement of air filters, regular tuning of the engine (Hedges, Djukic & Irving, 2007) Monitor emissions and record backpressure on exhaust treatment devices at each routine service (Hedges, Djukic, & Irving, 2007)
PPE	Use of respiratory protection (OSHA, 2013)

Airborne hazards – risk control hierarchy

Elimination	Is often not possible to eliminate dust, especially when working with sand or concrete, or when undertaking tunnelling activities (Workplace Health and Safety Queensland, 2013).
Substitution	Use garnet as substitution for sand-if possible, use of aluminium oxide polishing powders instead of silica powders (Workplace Health and Safety Queensland, 2013) Use pilled solids instead of powders, using wet processes instead of dry ones or vacuuming instead of sweeping (Workplace Health and Safety Queensland, 2013).
Engineering	Use of ventilation systems (Workplace Health and Safety Queensland, 2013) Local exhaust ventilations are available as • Enclosing hoods • High velocity low volume hoods • Exterior hoods Implementation of vacuum cleaners *Suppression* Use water or fine mist suppression to control dust cloud (Workplace Health and Safety Queensland, 2013b) Additional water dust suppression should be applied for tasks which are outside during dry weather (Yale Environmental Health & Safety, 2009) or to control dust in mines (Prostański, 2013). Install a conveyor belt wash box where conveyor belts are in use (Cole, 2016) Implement dampeners to increase the air flow (Cole, 2016) Use sticky floor mats and barrier protections at the entrance to the working to reduce the amount of filth transferred to any other working areas (Yale Environmental Health & Safety, 2009) Provide fresh air by using controls like a canopy air curtain to over roof bolters operators (Listak & Beck, 2012) and enclosed cabin filtration systems (Organiscak, Cecala, & Noll, 2013) For tasks where asbestos may occur the following additional controls should be considered: • Implement barrier protections at the entrance to the working area • Use sticky floor mats to reduce the amount of dust or debris transferred to any other working areas (Yale Environmental Health & Safety, 2009). • Use thickened substances such as pastes and gels to cover the surfaces of asbestos being worked on (Safe Work Australia, 2016) • Use shadow vacuuming (Safe Work Australia, 2016)

Administrative	Housekeeping, signage (Workplace Health and Safety Queensland, 2013) Restricting time of exposure (Workplace Health and Safety Queensland, 2013) Dust-generating tasks, such as dry brush sweeping, and the use of compressed air or reuse of vacuum filters should not be performed (Cancer Council Australia, 2017a) Dust-generating work must not be carried out on high wind days (Yale Environmental Health & Safety, 2009) Job rotation to reduce the time spent in the dusty areas (Workplace Health and Safety Queensland, 2013). Train the employees how to use PPE correctly and which PPE is appropriate for the task. Inform workers about risk of exposures and instruct them how to protect themselves (HSE, 2015) Health monitoring should be conducted regularly Drinking, eating and smoking is forbidden while working in areas where asbestos may occur (AUVA, 2015) Disposable shoe covers or overalls should removed before leaving the working area. If covers aren't used, clean shoes and clothing before leaving (Yale Environmental Health & Safety, 2009, AUVA, 2015) Provide washing facilities as close as possible to the working area. Provide mild skin cleansers and clean soft paper or towels for drying (HSE, 2015) Encourage workers to wash areas of their skin which might have been exposed and to use pre-work creams, if necessary, before starting work or after a break (HSE, 2015) In the case work of outdoor work, dust-generating activities should be avoided on high wind days (Yale Environmental Health & Safety, 2009) Construction debris should be covered and netted when removed. It should also be removed through an approved route, if possible during off peak times (Yale Environmental Health & Safety, 2009) Health monitoring must include a physical examination of the worker with a focus on the respiratory system (Safe Work Australia, 2016)

	Additional H&S training or awareness programs to increase workers understanding of the risk with a specific task, environment or material-related activity
PPE	Workers should wear appropriate filters: • P1 filters are for mechanically generated particulates like silica or asbestos • P2 filters are for thermally and mechanically generated particulates like metal fumes • P3 requires a full face mask and can be used for all particulates including highly toxic materials like beryllium (The University of Western Australia, 2016) • For tasks where asbestos may occur: • In addition to other control measures, PPE is necessary when working with asbestos. This includes coveralls, respiratory protective equipment, footwear and gloves. • AUVA (2015) recommends using closed eye goggles for any kind of overhead or demolition work and workers should be provided with gloves and hand protection creams (AUVA, 2015)

Noise – risk control hierarchy

<table>
<tr><td>Elimination</td><td>Avoid the usage of noisy machinery or processes, removing noisy operations away from other work activities (IOSH, 2018, Safe Work NSW, 2018a)</td></tr>
<tr><td>Substitution</td><td>Use alternative methods and equipment where appropriate (IOSH, 2018, BGHM, 2013 and OIR & WorkCover, 2017). Substitution strategies include replacing noisy equipment or machines with quieter ones (IOSH, 2018, Safe Work NSW, 2018a, OIR & WorkCover Queensland, 2017):
<table>
<tr><th>Source of noise</th><th>Alternative</th></tr>
<tr><td>work machines and equipment</td><td></td></tr>
<tr><td>solid wheels</td><td>rubber tyres</td></tr>
<tr><td>fuel engines</td><td>electrical engines</td></tr>
<tr><td>rollers</td><td>conveyor belts</td></tr>
<tr><td>metal chutes and containers</td><td>rubber or plastic chutes and containers</td></tr>
<tr><td>pneumatic tools</td><td>electrical tools</td></tr>
<tr><td>metal gears</td><td>plastic gears</td></tr>
<tr><td>metal bearings</td><td>fibre bearings</td></tr>
<tr><td>rolling bearing</td><td>slide bearing</td></tr>
<tr><td>impact wrenches</td><td>hammer drills</td></tr>
</table>
Substitution strategies may also include a modification of working methods or proceedings to reduce noise (IOSH, 2018, BGHM 2013 and OIR & WorkCover Queensland, 2017):
<table>
<tr><th>Source of noise</th><th>Alternative</th></tr>
<tr><td>working methods</td><td></td></tr>
<tr><td>riveting</td><td>welding</td></tr>
<tr><td>discharging</td><td>evacuating</td></tr>
<tr><td>flanging with a hammer</td><td>using a Kraft former machine</td></tr>
<tr><td>using a nibbling machine</td><td>using a laser cutting machine</td></tr>
<tr><td>acoustic signalling</td><td>optical signalling</td></tr>
<tr><td>marking the punching unit with a punch</td><td>using a centre to punch</td></tr>
<tr><td>hammering</td><td>gluing</td></tr>
<tr><td>stapling</td><td>clipping</td></tr>
<tr><td>chipping</td><td>grinding</td></tr>
<tr><td>forging</td><td>pressing</td></tr>
</table>
</td></tr>
</table>

	Use alternative equipment where appropriate and buying quieter equipment (LHSFNA, 2014, Safe Work NSW, 2018a)
Engineering	Modifications of tools and machines can also help to reduce noise: Add vibration isolation mountings, mufflers, laggings and silencers where possible to reduce noise (IOSH, 2018, OIR & WorkCover Queensland, 2017, Safe Work NSW, 2018a) Provide wear-resistant rubber or plastic coatings to reduce acoustic sounds Stiff / fix damping materials to panels or other surfaces to reduce noise impact of items during processing (OIR & WorkCover Queensland, 2017, Safe Work NSW, 2018a) Add noise barriers and / or noise enclosures (IOSH, 2018, OIR & WorkCover Queensland, 2017, Safe Work NSW, 2018a) Use noise dampening mats to reduce heavy equipment noise (Salah et al., 2017) Use acoustical silencers in intake and exhaust systems (such as internal combustion exhaust systems or air conditioning systems) (OIR & WorkCover Queensland, 2017, IOSH, 2018) Implement acoustical silencers in intake and exhaust systems (such as internal combustion exhaust systems or air conditioning systems) (OIR & WorkCover Queensland, 2017, IOSH, 2018, Safe Work NSW, 2018a) Use a sound-reducing enclosure that fully covers the machine(s) (IOSH, 2018, OIR & WorkCover Queensland, 2017)
Administrative	Replace worn bearings and or gears and maintain machines regularly (IOSH, 2018, OIR & WorkCover Queensland, 2017, Safe Work NSW, 2018a) Maintain optimum speed of machinery or its particular components (IOSH, 2018) Implement noise perimeter zones (LHSFNA, 2014) Train the workers in the correct use of personal hearing protectors and when to wear them (OIR & WorkCover Queensland, 2017, Safe Work NSW, 2018a). Schedule the work according to the noise level. Noisy work should be done when there are minimal people on the worksite. Inform workers when noisy work will be carried out Keep workers out of noisy areas especially if they do not have to be there as part of their job. Provide quiet areas for breaks

	Restrict the time workers spend in noisy areas Implement a job rotation scheme (Safe Work NSW, 2018a) Purchase new plant and equipment that produces less noise (IOSH, 2018, OIR & WorkCover Queensland, 2017, LHSFNA, 2014, Safe Work NSW, 2018a) Identify hearing protection zones and clearly sign-posting noisy areas (OIR & WorkCover Queensland, 2017, Safe Work NSW, 2018a) Monitor workers to ensure they wear hearing protection (OIR & WorkCover Queensland, 2017, Safe Work NSW, 2018b)
PPE	Provide personal hearing protectors of correct rating suitable for the work conditions (OIR & WorkCover Queensland, 2017, Safe Work NSW, 2018b)

Heat stress – risk control hierarchy

Elimination	Stopping work
Substitution	Safe Work Australia (2013) identifies substitution measures that reduce the extent to which workers are exposed to heat: Use automated equipment or processes to access hot locations. For example, use a drone to inspect a fire ground. Where possible, have workers do the work elsewhere Install automated or remote-controlled machinery so that workers don't have to do physically demanding work by hand Use plant or other equipment to reduce manual labour (For example, use a crane or forklift to lift heavy objects) Substitute heat generating plant and equipment (Rowlinson, et al., 2014)
Engineering	Provide extra ventilation in enclosed workplaces which have the possibility of becoming hot (Safe Work Australia, 2013, Rowlinson et al., 2014) Modify ventilation, regulate air flow, provide extra fans for low air flow areas, refrigerate air / water supply (Safe Work Australia, 2013a) Include shelters to reduce heat gain (Rowlinson et al., 2014) Implement shade structures to reduce surface heat exposure (Safe Work Australia, 2013a) Site sheds and facilities should also be provided with air-conditioning (Rowlinson et al., 2014)
Administrative	Job rotation of the workers in hot areas (Rowlinson et al., 2014, Safe Work Australia, 2013a) Provide drinking water for the workers (Rowlinson et al., 2014, Safe Work Australia, 2013a) Provide guidelines for fluid intake under different conditions (Kenefick & Sawka, 2007) Provide hygiene facilities (Rowlinson et al., 2014) Establish a risk assessment system and establish surveillance (Rowlinson et al., 2014) Consider a personal heat risk assessment checklist for workers (Rowlinson et al., 2014)

	Enable self-pacing (Rowlinson et al., 2014) Implement regulations for work and rest according to the general health, body weight, level of physical fitness and (if any) medication taken by each worker (Safe Work Australia, 2013a) Organise work to minimise physically demanding tasks, for example conduct work at ground level to minimise climbing up and down stairs or ladders (Safe Work Australia, 2013b) Modify targets and work rates to make the work easier and reduce physical exertion (Safe Work Australia, 2013b) Ensure workers are not working alone, or if they must work alone, monitor them and make sure that they can easily call for help (Safe Work Australia, 2013b) Implement mandatory breaks (Rowlinson et al., 2014) Consider an assessment of workers' hydration levels Provide workers with information and training about the risks and symptoms of heat stress (Rowlinson et al., 2014, Safe Work Australia, 2013a) Introduce a hydration program (Kenefick & Sawka, 2007)
PPE	Provide cooling vests (with gel or circulating liquids) and shade hats (Safe Work Australia, 2013a) Modify uniforms or required dress codes so workers can wear cooler, more breathable clothing (Safe Work Australia, 2013b), for example Chan et al. (2016) developed and evaluated an anti-heat stress work 'uniform' that has become standard industry requirement in the construction industry of Hong Kong

Vibration – risk control hierarchy

Hand-arm vibration

<table>
<tr><td>Elimination</td><td>Where appropriate automate or mechanise the work

Use alternative methods if it is technically appropriate. For example, a breaker attachment on an excavating machine should be used to break concrete instead of using a hand-held breaker (HSE, 2011)</td></tr>
<tr><td>Substitution</td><td>Change work methods (e.g., use a diamond-hole cutting drill with rotary action instead of a tungsten-tipped hole bit to reduce the exposure time (HSE, 2011)

Use alternative equipment which reduces the duration of the vibration instead of using hand-held hammers and / or breakers, where possible such as:
machine-mounted hydraulic breakers
floor saws
directional drilling/pipe jacking to avoid trenching
hydraulic crushers
hydraulic bursters
diamond core drilling
diamond wire cutting (HSE, 2011)
Consumables: use equipment and consumables which claim to reduce vibration such as saw blades or ceramic abrasives (Shanks, Hunwin, & Mole, 2013)

Workstations should be designed in a way that they minimise loads on employees' hands, wrists and /or arms (HSE, 2011)</td></tr>
<tr><td>Engineering</td><td>Use vibration reducing devices, such as:
Anti-vibration side handle
Comfort grips
Tensioners / spring balances
Resilient coatings
Grinding wheel balancers
Rear handle bushing
Drilling rigs
Saw clamping system
Elephant trunk suspension system
Vibration reducing flange
Two chisel sleeves (Shanks, Hunwin, & Mole, 2013)
Use alternative methods to remove pile cap instead of hand-held hammers/ breaker, use methods such as
Elliott Method or the
Recepieux Method (HSE, 2011, 2002)
Plan to avoid unnecessary drilling and if possible, use:
jig-mounted drilling
diamond core drilling (clamped in rig)
cast-in anchors and channels for wall fixings instead of drill-and-fix types</td></tr>
</table>

	• use of direct fastening tools instead of electric hammer drills (HSE, 2011) • provide suspension seats (Griffin et.al, 2007)
Administrative	Limit the use of high-vibration tools Plan work with several shorter periods instead of long ones (HSE, 2011) Provide training for the purchasing staff to purchase equipment and consumables which reduce vibration levels (HSE, 2011) Provide training on how equipment can be used to minimise vibration (HSE, 2012b) Provide training on the risks of vibration Maintain all devices and equipment regularly to prevent an increase of vibration (HSE, 2011) Use correct equipment (not damaged), replace old equipment (HSE, 2011) Limit or reduce the time that employees are exposed to vibration by job rotation and shorter duration being exposed to vibration (HSE, 2011) Arrange regular breaks for workers who are exposed to vibration. Encourage the workers / operators to exercise their fingers (HSE, 2011)
PPE	Provide clothing which encourages blood circulation

Whole-body vibration

Elimination	Introduction of remotely controlled mobile plant rather than plant driven by workers.
Substitute	Purchasing or hiring mobile plant, which has lower vibration emissions or is more suited to the task. Isolating or dampening a work platform to eliminate or minimise vibration from a motor using rubber mounts and flexible connection
Engineering	Insulating seats and head rests through incorporation of spring and dampers (HASPA, 2012) Vehicles must be provided with suspension seats and include seat springing (Griffin et al., 2007) Tyre types must be selected according to the terrain. In addition, suspension, roadways and tyres must be regularly checked Uneven surfaces should be smoothed on construction sites (OSHA, 2006)
Administrative control	Limiting the speed at which vehicles travel depending on terrain conditions (HASPA, 2012) Introducing a roster system to minimise how long each worker is exposed to WBV Incorporating mini breaks on regular basis (HASPA, 2012) Incorporating seat maintenance and replacement programs (HASPA, 2012) Maintaining roads and other surfaces in good condition (reasonably practicable) (HASPA, 2012) Providing training to workers about the risks of vibration is necessary (HSE, 2012b). Safe Work Australia (2016b) recommends that training must cover information about the sources of WBV and how the vibration can be minimised (e.g. with proper seat adjustment) as well as how to recognise and report symptoms. Canadian Centre for Occupational Heath and Safety (2018) also recommends that all equipment must be well maintained in cyclic periods to avoid excessive vibration.
PPE	Workers standing on a vibrating platform may benefit from shoes with soles designed to reduce transmission of vibration to the feet Provide clothing which encourages blood circulation

Ultraviolet radiation – risk control hierarchy

Elimination	In the case of UV from the sun, carry out the work indoors – (Safe Work Australia, 2013b)
Substitution	Move work to existing shade at the worksite, such as shade from trees and/or buildings (Safe Work Australia, 2013b) Change or avoid reflective surfaces to reduce reflective UVR (Cancer Council Australia, 2017b)
Engineering	Install shade structures over (outdoor) work sites and rest areas (Queensland Government, 2010, Safe Work Australia, 2013b), such as portable sun shades (Safe Work Australia, 2013b) Apply tinted or clear films to the side windows of vehicles to reduce the amount of UVR exposure If the UVR exposure is from a non-solar source, such as from welding, engineering controls, such as door interlocking power supplies, UVR blocking filters or opaque barriers should be considered (WHO, 2003)
Administrative	Conduct a risk assessment (identify workers who have a high risk of exposure and also situations in which high exposure occurs) (Safe Work Australia, 2013b) If possible, carry out outdoor work in the early morning and / or late afternoon when the level of ultraviolet radiation is lower (Safe Work Australia, 2013b) Schedule indoor or shaded work tasks when levels of UV are strongest (Safe Work Australia, 2013b, Queensland Government, 2010) Rotate the workers to reduce the time exposed to the sun (Safe Work Australia, 2013, Queensland Government, 2010) Increase the number of workers to reduce the individual exposure time (Queensland Government, 2010) Vary the tasks to reduce the exposure time (Queensland Government, 2010) Encourage employees to move to shaded areas (Safe Work Australia, 2013, Queensland Government, 2010) Provide shaded outdoor or indoor areas for breaks (Safe Work Australia, 2013b, Queensland Government, 2010) Increase lengths and duration of breaks (Queensland Government, 2010)

	Encourage workers to switch/ rotate between outdoor, indoor and shaded work tasks with the aim to reduce the exposure time (Safe Work Australia, 2013b) Provide daily information about the UV Index and encourage workers to use an UV alert on their smartphones (Safe Work Australia, 2013b) Provide health check-ups / health surveillance such as regularly skin and eye checks for the exposed workers (Queensland Government, 2010) Inform / train workers (how) to work safely in the sun. (Cancer Council Australia, 2017b, Safe Work Australia, 2013) Training should also include a correct application and usage of personal protective equipment. Workers should be instructed on how to examine their skin effectively (Safe Work Australia, 2013b) Implement sun protection practices during work related events (Safe Work Australia, 2013) Promote the use of sun protection practises after work and on the weekends (Safe Work Australia, 2013b) Ensure supervisors, managers and foremen act as positive role models (Safe Work Australia, 2013b) Inform workers about the harmful effects of UV exposure and the risks on the worksite (Queensland Government, 2010, Safe Work Australia, 2013b) Consider implementing wearable UVR trackers to monitor exposure (and to provide readings and warnings when dangerous levels of UVR exposure are reached) (Gizmodo, 2017) If UVR exposure is from a non-solar source administrative control measures include warning signs Workers should keep a safe distance from the UVR source and strict time limits should be imposed on work while emitting machinery is switched on (WHO, 2003) Monitor and review control measures regularly (Queensland Government, 2010)
PPE	Provide PPE, such as sun protective hats (broad brimmed; covering the neck, ears, head and face), sunglasses (which meet the Australian Standards), sun protective work clothing long-sleeved / close weaved shirts with collars , knee long shorts or trousers, sunscreen (at least SPF 30 or higher, preferably water resistant) (Safe Work Australia, 2013b, Queensland Government, 2010), lip balm (at least SPF 15 or higher) (Queensland Government, 2010).

	Consider providing fabric patches in protective clothing and workwear which indicates, when the protective performance of clothing has been degraded (Pościk, 2013).

Psychosocial hazards – risk control hierarchy

Elimination	Redesign work practices: Review job scheduling or change work time arrangements (such as compressed work weeks to enable a five day working week) (Lingard et al., 2008) Redesign work contracts to eliminate job insecurity Change task characteristics or other work conditions Address issues of role clarification and social relations in the workplace Provide work-family programs
Substitution	Provide awareness training Provide coping resources, for example time management or stress management programs Provide and promote organisational and supervisor support
Engineering	Not applicable
Administrative	Implement guidelines and policies establishing rules about how to respond to bullying allegations and conflicts in the workplace, as well as aggression or violence anti-bullying campaigns (Health & Safety Authority and National Treasury Management Agency, 2017). Promote social support Implement health circles (Semmer & Zapf, 2004)
PPE	Not applicable