Centre for
Construction Work Health and Safety Research

Engaging stakeholders in improving the quality of OSH decision-making in construction projects

Research to Practice Report

April 2015

RMIT UNIVERSITY

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Helen Lingard, Nick Blismas, Rita Peihua Zhang, Payam Pirzadeh, Kevin Jones, James Harley, Ron Wakefield

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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 organizations to analyze health and safety (H&S) performance and identify opportunities for improvement. We can develop and evaluate innovative solutions, provide specialized 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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Figure 4.6: courtesy Mark Vines, RMIT University
Figure 4.7: courtesy Rita Peihua Zhang, RMIT University

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Part 1: Executive summary

Traditionally the construction industry has performed poorly in terms the occupational safety and health (OSH) of its workers.

Research undertaken in the United States and Australia had three aims, to investigate:

(i) the benefits associated with early consideration of construction workers' OSH in the life cycle of a construction project,

(ii) the role played by communication and social networks in supporting positive OSH outcomes in construction projects, and

(iii) ways to ensure that project team members work collaboratively and cooperatively to produce good OSH outcomes.

This report illustrates the importance of early OSH intervention in construction projects, the important role of communication and consultation in achieving safety and OSH improvements and, perhaps most importantly, provides simple tools for identifying OSH benchmarks from which a strategy for improvement can be built.

How to use this report

This report is constructed in two sections. The first identifies the research that shows, through Case Examples and other data, the most effective pathway toward OSH improvements including the importance of five best practice principles:

Principle 1: Address health and safety as early as possible in the project,
Principle 2: Identify and consult all relevant stakeholders,
Principle 3: Ensure construction process knowledge is available to decision-makers,
Principle 4: Implement the "hierarchy of controls" in decision-making, and
Principle 5: Review and continuously improve performance.

Fundamental to these principles is the consideration of the hierarchy of controls (HOC) to identify hazard control measures in a structured strategic manner.

The second section provides numerical and visual tools and templates that apply an evaluative method to the HOC that can turn the theory into practice.

Part 2: Overview

2.1 Introduction

Poor safety performance of the construction industry

The construction industry performs relatively poorly in occupational safety and health (OSH). Traditionally, on-site OSH has been interpreted as the responsibility of the construction firm, i.e., as the employer of construction workers. OSH initiatives by construction firms, including the implementation of robust and regularly audited OSH management systems have led to significant improvements in the industry's OSH performance. However, there remains a residual level of workplace death, injury, and illness that is resistant to change.

In 2010, the U.S. construction industry accounted for 802 (17.1%) of the total 4,690 fatal work injuries reported in the United States in addition to 75,000 non-fatal injuries resulting in days away from work[1]. In 2013, despite a slight decrease in the total number of fatal injuries (3,929), the construction industry recorded a similar number of fatal work injuries (796) thus accounting for 20.3% of the total fatal injuries in the United States[2].

In Australia, in 2013, the construction industry accounted for 10% (19 fatalities) of the total 191 fatal injuries for workers[3]. Moreover, over the five years from 2007 to 2012, 211 construction workers died from work-related injuries, resulting in the total number of deaths equating to 4.34 fatalities per 100 000 workers, which is nearly twice the Australian national rate of 2.29 for the same period of time. During these five years, the construction industry also accounted for 11% of all serious workers' compensation claims with an average of 39 claims each day from employees who required one or more weeks off work because of work-related injury or disease[4].

These occurrences are preventable as most of them arise from well-understood hazards which can be controlled through the adoption of known risk elimination/reduction interventions and solutions.

Thus far, the majority of OSH efforts in construction have been implemented at the level of the construction firm, although there is a growing recognition that the root causes of OSH incidents can be traced back to problems inherent in industry-level systems of work.

There is emerging evidence that to make further impacts and to address the intransigent residual level of injury, illness, and death in construction, a 'whole industry' approach is required.

1 Centre for Construction Research and Training (2013), C*onstruction chart book: The U.S. construction industry and its workers* (5th ed.), Center for Construction Research and Training, Silver Spring, MD.

2 U.S. Department of Labor, Occupational Safety & Health Administration, Viewed in April, 2015, at: https://www.osha.gov/oshstats/commonstats.html

3 Safe Work Australia (2014), Work-Related Traumatic Injury Fatalities Australia 2013, at: http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/870/Traumatic-Injury-Fatalities-Report-2013.pdf

4 Safe Work Australia (2013), Construction Fact Sheet, at: http://www.safeworkaustralia.gov.au/sites/swa/about/publications/pages/fs2010constructioninformationsheet

Aim

This report documents research undertaken as part of a five year benchmarking study of construction OSH between the United States and Australia.

The research aimed to investigate:

(i) the benefits associated with early consideration of construction workers' OSH in the life cycle of a construction project,

(ii) the role played by communication and social networks in supporting positive OSH outcomes in construction projects, and

(iii) ways to ensure that project team members work collaboratively and cooperatively to produce good OSH outcomes.

The research findings and practical tools developed in the research are presented in this report.

The report is structured as follows:

Part 1 provides the background to the research and identifies some key challenges to integrating OSH into the management of construction projects and establishes five 'best practice' principles that flow from the research that can underpin the effective integration of OSH into construction project management.

Part 2 explains each of these principles in more detail providing the research evidence that supports them and uses case examples to illustrate each principle.

Part 3 provides two tools/resources developed in the research that can be used by construction project teams to: (a) understand and evaluate the quality of their OSH efforts, and (b) explore OSH risk perceptions and develop shared mental models of OSH in project teams.

Industry need

Calls for 'upstream' intervention to improve construction OSH

Most contemporary models of accident causation recognize the importance of organizational issues and management actions in contributing to workplace accidents. Some construction accidents can be, at least in part, attributed to failures arising before work commences on site. For example, decisions taken in the project planning and design stages have been linked to construction site accidents.

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

- government and OSH regulators, owners/clients,
- the numerous contributors to the design of a building or structure,
- constructors,

- specialist sub-contractors, and
- suppliers of plant, equipment, and materials.

There is a need:

- to identify the fundamental principles upon which a ‘whole industry’ approach to improving construction workers’ OSH can be founded,
- to better understand the mechanisms by which an integrated and effective approach to managing OSH in construction projects can be realized, and
- to develop practical tools that can help industry participants to better manage OSH through the entire construction project life cycle.

The research described in this report addresses this need.

Industry fragmentation

The construction environment is much more complex than single organization environments in which senior managers establish OSH policy that is translated into practice through a process of planning, resourcing, coordinating, and monitoring performance. The delivery of a construction project is characterized by complex inter-organizational relationships, information dependencies, and considerable division of labor.

Construction projects are delivered by several organizations across many teams. There is growing recognition that many contributors to construction projects either make or influence decisions that have the potential to impact construction workers’ OSH. In fact, in some instances, OSH hazards/risks in the construction environment can be traced back to decisions made before the construction work commences.

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

Perhaps unsurprisingly, the fragmentation of the construction supply chain has been identified as a critical factor in the emergence of OSH problems in construction projects. The development of a unity of purpose with regard to construction workers’ OSH 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 OSH, many contractual arrangements deflect responsibility from one contributing party to another. Indeed, industry discussions concerning the allocation of OSH responsibility in construction projects are underpinned by a culture of ‘finger-pointing’ and allocating blame. This can hinder genuine attempts to embed OSH in management processes across the life cycle of construction projects.

Policy push for a more integrated approach

Construction Hazard Prevention through Design (CHPtD) has become a key focal point of industry policy in many countries. In Australia, OSH legislation establishes specific requirements for designers to identify and reduce the OSH risks inherent in the design of structures or their components.

Despite the growing emphasis on integrating OSH consideration into project decision-making in the planning and design stages of projects, the extent to which OSH has actually been improved by these policy initiatives remains unclear. One challenge lies in the degree to which there is vertical segregation between participants engaged in the initiation, design, production, use and maintenance of facilities. In particular, the traditional separation between the design and construction function can impede the development of shared project goals and can negatively impact project outcomes.

Other practical challenges associated with the implementation of CHPtD have also been noted. In particular, concerns have been raised about the lack of OSH education in tertiary education programs undertaken by design professionals. There are also concerns that the traditional project procurement strategies may limit access to OSH knowledge in the design phase of construction projects.

Questions also arise as to how easy it is to attribute responsibility for CHPtD to individuals or organizations on the basis that they occupy abstract socio-technical roles, such as “the designer.” Construction project design work comprises a network of tasks, requiring contributions from many different specialists. The design process relies on the exchange of information and frequent and detailed interaction between these specialists in order to ensure that the components of a building/structure, which must fit together, are compatible. Activities and interfaces between specialists form a complex network of design activity. For CHPtD to be effective, interventions and recommendations need to reflect the complexity and variety of the social and technical arrangements for delivering construction projects.

To facilitate a ‘whole industry’ approach, a better understanding of how structural and organizational characteristics of the construction industry impact OSH performance is needed.

International benchmarking research project

The research used a socio-technical system to assess how social networks and communication patterns affect the application OSH risk controls. In particular, the research explored the influence and impact of multiple stakeholders, some of whom are not traditionally considered to be part of the construction project team. The need to systematically measure the quality of OSH outcomes to evaluate how effectively OSH is being managed in construction projects became apparent and a proactive measurement tool based upon the hierarchy of controls was developed and tested in the research. The research also examined the way in which project team members understand and respond to OSH hazards associated with various construction technologies. Points of similarity and difference between industry participants who represent different professional groups (architects, engineers, constructors and OSH professionals) were explored. Opportunities to understand OSH hazards from different perspectives and to develop shared mental models of OSH in project teams were identified in the research.

This report is intended to help industry participants utilize the findings of the research to improve OSH in construction projects.

2.2 The principles

Five best practice principles for improving the management of OSH in construction projects were identified from the research. These are:

- Principle 1: Address health and safety as early as possible in the project,
- Principle 2: Identify and consult all relevant stakeholders,
- Principle 3: Ensure construction process knowledge is available to decision-makers,
- Principle 4: Implement the hierarchy of controls in decision-making, and
- Principle 5: Review and continuously improve performance.

Each of these principles is briefly described below and described in more detail in Part 2 of this report.

Principle 1: Address health and safety as early as possible in the project

Decisions taken during the planning and design stages of a construction project can have significant impact on the OSH of construction workers. For example, decisions about the project delivery method, budget, work schedule and permanent works design all have potential OSH impacts. Generally, the earlier that OSH is considered in the life cycle of a construction project, the greater the ability to influence OSH outcomes. Indeed, opportunities to influence OSH are highest at the beginning of a project and become less and less as the project progresses.

Principle 2: Identify and consult all relevant stakeholders

Construction projects are delivered by several organizations, using multi-disciplinary teams. Many contributors to construction projects either make or influence decisions that have the potential to impact construction workers' OSH. Sometimes, these stakeholders may be external to the project, for example, regulatory authorities or community advocacy groups. It is important that the interests of stakeholders are understood and proper consultation and engagement processes are established to ensure that decisions made in response to key stakeholders' interests are consistent with the need to ensure the highest standards of construction OSH.

Principle 3: Ensure construction process knowledge is available to decision-makers

The construction industry supply chain is highly fragmented and there is often little communication between persons responsible for the initiation, design, production, use and maintenance of facilities (buildings or other structures). This can impede the development of shared project goals and negatively impact project OSH. The traditional separation and poor communication between the design and construction functions has been identified as a causal factor in fatalities and a barrier to the effective implementation of CHPtD.

Constructors are responsible for the actual construction operations in a project and thus have a strong motivation and interest in ensuring work can be performed with minimal risk to workers'

OSH. Compared to other project participants, constructors have a high level of knowledge about construction processes because of their specialized training and knowledge and experience in the application of construction materials and methods. Constructors are therefore able to provide advice about OSH to decision-makers before construction work commences. When expert knowledge about the construction process is fed into “upstream” decision-making, i.e., during the planning and design stages of a project, better decisions are made and there is greater likelihood that OSH hazards/risks will be eliminated or reduced at source.

Principle 4: Implement the hierarchy of controls in decision-making

In OSH, risk management is the process of:

1. Identifying hazards - i.e., anything in a workplace that has potential to cause harm, e.g., an unguarded edge, a confined space, a heavy object that needs to be lifted, work over water.

2. Assessing the risk associated with identified hazards – deciding how significant the risk is, e.g., will it cause a serious injury, illness or death and how likely is this to occur?

3. Controlling the risk – achieved by eliminating the hazard altogether or, if not practicable, reducing the level of risk presented; for example by relocating equipment, designing to provide safe access, provide lifting devices to reduce manual handling or providing anchorage points for the use of fall arrest devices or other controls.

4. Reviewing and monitoring – once a risk has been assessed and controlled, periodic monitoring should be undertaken to ensure the risk controls remain effective.

When selecting appropriate controls for OSH hazards/risks the hierarchy of controls (HOC) should be applied. The HOC classifies ways of dealing with OSH hazards/risks according to the level of effectiveness of the control. In descending order of effectiveness the HOC levels are:

- Elimination – this is the most effective form of control because the physical removal of the hazard/risk from the work environment means that workers are not exposed to it.
- Substitution – this involves replacing something that produces a hazard with something less hazardous.
- Engineering controls – these physically isolate people from hazards.
- Administrative controls – these include developing safe work procedures or implementing a job rotation scheme to limit exposure to a hazard.
- Personal protective equipment (PPE) – this is the lowest form of control.

Although, much emphasized and visible on a worksite, PPE should be seen as a last resort solution.

The top three (upper) levels of control (i.e., elimination, substitution and engineering) are technological because they change the physical work environment, making it safer and/or healthier. The bottom two (lower) levels of control rely on human behavior for their effectiveness. Controls that rely on human behavior are less reliable, since human beings make mistakes. This means that wherever possible, technological (upper level) controls for OSH should be selected.

Principle 5: Review and continuously improve performance

OSH management should strive for continuous improvement by regularly reviewing OSH performance, seeking feedback from project stakeholders, and using the lessons learned to improve performance and to share and promote best practices in the construction industry.

In order for the industry to maintain sustained improvement in OSH, clear targets and appropriate Key Performance Indicators should be established for OSH at an industry, organization and project level and OSH performance should be rigorously monitored and measured.

This measurement should incorporate traditional ‘lagging’, as well as proactive ‘leading’ indicators of OSH performance. The continuous improvement of OSH also requires industry-wide collaboration in the form of benchmarking and information sharing.

Regular reviews of OSH management performance should be undertaken through all stages of the project lifecycle. These should be conducted collaboratively between all project stakeholders including subcontractors.

Upon the completion of construction projects, a post-project review of OSH performance and processes of clients, designers and constructors should also be undertaken. This review should evaluate the extent to which these parties have worked cooperatively to apply OSH in the project. Lessons from these post-project OSH reviews should be captured and shared.

Part 3: Principles

3.1 Principle 1: Address health and safety as early as possible in the project

Introduction

In the construction industry, the argument that the opportunities to reduce OSH risk are highest at the beginning of a project and become less and less as the project progresses is often mentioned. Thus, in the early planning and design stages the ability to influence OSH is believed to be significantly greater than it is at the procurement stage. At the commencement of construction, the ability to influence safety is often thought to be very limited. This is shown in Figure 3.1.

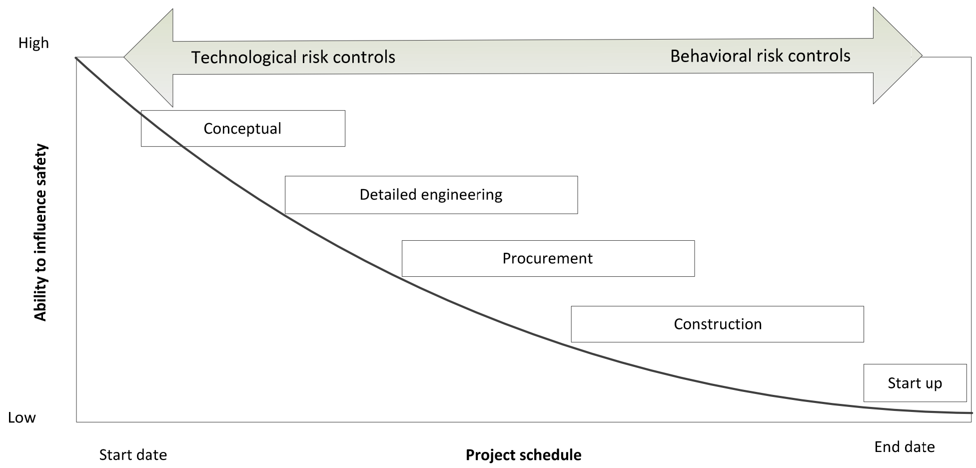

Figure 3.1: Time/safety influence curve[5]

It could be said leaving decisions about OSH to the construction stage of a project will produce poor results because key decisions and the OSH consequences that flow from them are already fixed. This means that design modifications implemented to improve OSH in the construction stage can produce improvements but often fail to eliminate an inherently dangerous activity. For example, fixing rails or anchor points for fall arrest devices are important OSH improvements that can be implemented during construction but these solutions do not eliminate the inherently dangerous activity, i.e., working at height. In the construction stage small modifications to the design of the construction process might be possible, but fundamental changes are often not possible to make at this point.

5 Figure adapted from Szymberski, R., (1997), Construction Project Safety Planning, *TAPPI Journal*, 80 (11), pp. 69–74. (Reproduced with permission)

The principle explained

The international benchmarking study research tested the proposition that early consideration of OSH in project decision-making would produce better outcomes. The study:

- measured the effectiveness of OSH risk controls in case study construction projects,
- identified whether OSH risk control measures were identified and developed before the commencement of construction; and
- examined whether OSH 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 OSH 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 OSH 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 consideration of OSH in the early stages of a construction project and the quality of risk controls implemented in the construction stage of the project. Thus, when OSH risks were identified and control decisions taken before the commencement of construction, it was more likely that OSH risks would be controlled at source, through the implementation of upper level control measures.

When decisions were left until the construction stage, it was more likely that measures implemented to control OSH risks using the lower levels of control that rely for their effectiveness on workers' behavior, for example administrative controls or personal protective equipment.[6]

This research provides some evidence for the link between early intervention in OSH, especially in the pre-construction stages of the project life cycle, and the implementation of controls for OSH hazards that make the construction work environment physically safer and healthier.

Thus the research supports the principle of considering OSH risks early in the life cycle of construction projects.

6 For a full description of these research results see Lingard, H., Saunders, L., Pirzadeh, P., Blismas, N., Kleiner, B. & Wakefield, R., (2015).The relationship between pre-construction decision-making and the effectiveness of risk control, *Engineering, Construction and Architectural Management*, 22 (1), pp. 108 – 124. http://dx.doi.org/10.1108/ECAM-08-2013-0074

3.2 Principle 2: Identify and consult all relevant stakeholders

Introduction

Construction projects have many stakeholders who can affect or be affected by the achievement of the project's objectives. Stakeholders can also be understood in terms of the potential harm and/or benefit that they experience as a result of a construction project. Construction workers are a very important stakeholder group when considering OSH. However, many other project stakeholders can deliberately or even unwittingly influence OSH performance in construction projects. Thus, in the management of construction project OSH it is helpful to:

1. identify who has input or influence over decisions which have the potential to affect (positively or negatively) construction workers' OSH,
2. understand how OSH could be affected by the actions or interests of individuals or groups,
3. understand how the configuration of influencers can change as a construction project progresses, and
4. engage stakeholders at an appropriate time and in an appropriate manner to ensure that OSH hazards are avoided and OSH risks are managed effectively.

The principle explained

Who is a stakeholder?

Project stakeholders who may have an interest in or who can influence OSH on construction projects may include:

- client representatives,
- project managers,
- design managers,
- lead and specialist design consultants,
- component manufacturers and suppliers,
- health and safety managers,
- environment managers,
- the construction manager and site supervisors,
- the end user's asset management team,
- subcontractors,
- community representatives,
- maintenance personnel,
- independent safety assessors/auditors,
- temporary works consultants, and
- other relevant stakeholders and subject matter experts.

It can be useful to categorize stakeholders as internal or external (see Figure 3.2). Internal stakeholders are entities which have entered into a contract (either formal or informal) with the client and can be further broken down into two subgroups, internal demand stakeholders and internal supply stakeholders. Internal demand stakeholders typically focus on the end use of the project and it is common for their needs and expectations to drive project briefs and specifications. Internal supply stakeholders provide services to the project. Depending on their role, they may have differing levels of interest and knowledge in construction process.

External stakeholders also have a direct interest in the project, but are not bound to the client through any contractual arrangement. These groups are much more diverse than the internal stakeholders and are more likely to serve the interests of an individual or the stakeholder group they represent rather than the client's planned project. Broken down into two sub-categories external stakeholders can be identified as being either private or public. External private stakeholders might include concerned individuals, trade associations, environmental and conservationists associations, neighborhood associations, and the like. External public stakeholders might include local governments, state governments, federal regulatory agencies, federal governments, or international agencies.

External stakeholders can have a substantial influence on decisions made during the planning and design stages of a construction project. Given the direct link between planning and design decisions and construction workers' OSH, these stakeholders can also influence OSH outcomes (either consciously or unconsciously). There is proven value in engaging multiple stakeholders in hazard identification workshops in the planning stage of a construction project to make sure that different perspectives are considered and that OSH hazards are not overlooked.

By engaging with stakeholders early, the positive impact of stakeholders' inputs can be maximized and negative impact minimized.

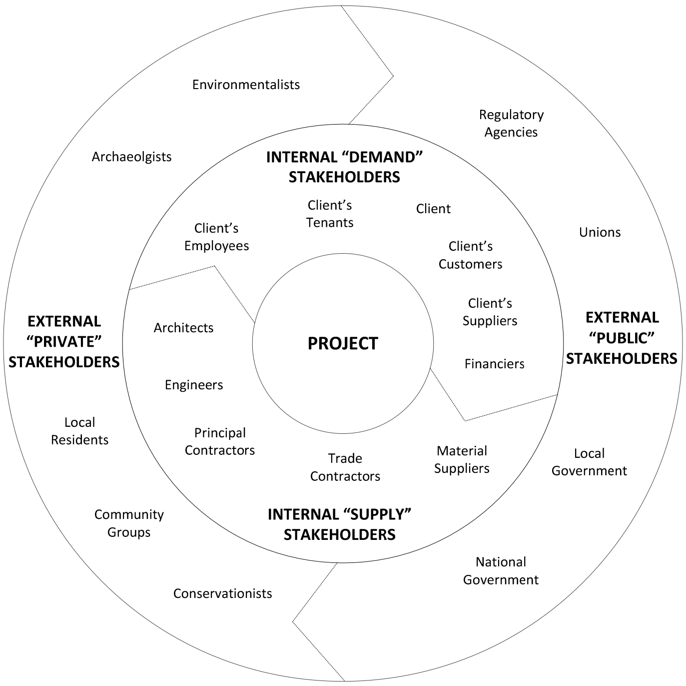

Figure 3.2: Stakeholder model [7]

[7] Figure adapted from Winch, G. M., (2010), *Managing construction projects*. John Wiley & Sons, UK. (Reproduced with permission)

Stakeholders' interests and OSH

The concerns and priorities of stakeholders change over the life of a construction project, influenced by outside events as well as decisions made by the project team.

Further, new groups of stakeholders may take an interest in the project in response to changing circumstances. Stakeholders' understanding of what they want develops through their reflection on decisions made through the life of the project and project requirements can develop in response to the interaction between emerging solutions and stakeholders' interests. OSH can be significantly affected by decisions made in response to key stakeholders' interests.

In the early design stage of a construction project, a flexible and collective process is suggested where stakeholders may negotiate compromises or 'trade-offs' to achieve workable solutions to new problems. In all cases, the implications for OSH should be systematically assessed and managed.

The following examples (3.1 to 3.3) illustrate the importance of identifying and consulting with all relevant stakeholders through the decision-making process.

Case Example 3.1 – Client's customers influence OSH in a suburban train station platform

The case arose during the design and construction of a suburban train station.

The original concept design involved the construction of a new 'island' platform, built between two existing and fully functioning rail lines. A pedestrian footbridge was to be built, spanning the full width of the tracks. Access to the platforms from the footbridge was to be provided by stairs at either end and in the middle of the footbridge. In accordance with disabled access requirements, an alternative means of accessing the platform by provision of a lift was also included in the original concept design.

However, before the contract was awarded, an incident occurred at a similar rail station. This incident involved the death of a passenger who could not be removed safely from an island platform because the ambulance trolley would not fit in the platform lift. Consequently, paramedics were forced to remove the passenger by walking over 'live' rail tracks.

In addition to concerns about access to and egress from station platforms, there were a number of passenger complaints about station lifts breaking down. A review of design policy for rail stations by the state government introduced new requirements specifying that all new stations would be installed with lifts able to accommodate a standard ambulance trolley and an alternative means of access in the form of a ramp would also be provided. This new policy was introduced shortly after tenders closed for the railway station project and companies that had tendered for the project were given two weeks to amend their proposals.

The contract was eventually awarded to a design and construction contractor on the basis of a proposal that included a number of changes to the original concept design. One of the main changes was the addition of a ramp for disability access. The late inclusion of a ramp in the design resulted in emergent hazards during the construction stage which were not envisaged at the tendering stage. The contractor commented:

> "When we priced and sketched up [the proposed design] at tender stage, no ramp was included. We were only given two weeks. We had already put our price in and it was a last minute change by the client….. No one picked up at the time about the canopies being bisected [by the ramp]".

A post-award risk assessment (involving the client, the rail operator and design and construction contractor) was conducted once the project commenced. This risk assessment focused primarily on the health and safety of end users of the station. The risk of persons jumping over the ramp balustrading onto an adjoining canopy was identified as a major risk. To address this risk, 'throw screens' were designed to be fixed to the ramp balustrading to reduce the risk of people climbing or throwing objects over the side. The risk assessment also identified the need to provide landings at regular intervals on the ramp to provide 'rest' areas.

The addition of the ramp, the landings and throw screens had a significant impact on the design and construction of the station. The sizing of columns supporting the ramp had to be substantially changed, with some columns more than doubling in size due to the inclusion of landings and throw screens. Size increases to the platform's steel structure were also required to safely support the increased loads associated with the ramp and larger columns.

As a result of these changes, construction workers' exposure to hazards associated with crane lifts was significantly increased. Additional platform components needed to be lifted into place and the larger size of structural members reduced manoeuvrability and increased risk. Workers' ability to control these lifts was a particular safety concern and the rail lines had to be closed on the days of the lifting operations. Further, the reduced clearance between the underside of platform beams, which had doubled in depth, and the ground meant that services originally planned to be connected to the underside of each beam had to be relocated due to restricted access clearances. Thus, a series of holes had to be cut into every intersecting beam for the length of the platform (approx. 100m), to allow conduit to be installed to accommodate services. The steel beams had been fabricated without any penetrations, so the in-situ cutting of holes presented new hazards associated the use of cutting equipment in an area that was already difficult to access.

Case Example 3.2 – The OSH impact of engaging internal stakeholders early during flood recovery activities on a rural road

The case involved flood recovery activities on a rural road where significant damage had been sustained as a result of excessive floods. The project involved reconstruction works at different locations on the road to rectify the damage to drainage, formations, pavement and a bridge structure.

The project used an accelerated delivery method. From the beginning of their appointment, the managing contractor emphasized a high level of communication among key stakeholders during the decision-making process. During the design stage, the managing contractor tried to involve each key stakeholder in decision-making to ensure that all parties' expectations were met and to avoid future conflicts or problems. Consequently, most of the stakeholders deemed design outcomes to be positive and attributed the good design solutions to the high level of communication and information exchange that occurred during the project. For example, when the client representative was asked about the level of communication that occurred between his organisation and the managing contractor, he stated:

> "It was good, they probably did more than they were required to do. They kept us up-to-date with what was happening, we got feedback and information and they picked up on everything we wanted."

The engagement of relevant stakeholders during the early design stage was facilitated by weekly design meetings and "safety in design" reviews conducted on site. The majority of stakeholders regarded the early design meetings as an enabler for integration of stakeholders' previous experiences in decision-making and improving the design outcomes. The consultation and stakeholder engagement also enabled the early identification of design aspects that could have a high level of impact on OSH and constructability. For example, as part of the recovery works, the constructor was required to construct retaining walls on the road sides to avoid future slip failure of the embankments. The original plan was to use soldier piles and light-weight ill to restore the road. However, after consultation with other sub-contractors who had done similar jobs in the area, the constructor realized that drilling soldier piles into the ground would not be safe and easy due to unfavourable ground conditions and high ground-water level. Thus a gabion wall was considered as the final practical and safe option.

In another case, a pedestrian bridge along the road had been damaged by the floods and required rectification. Spanning over a creek, the bridge deck consisted of two longitudinal sections joining on a crosshead on top of middle pillars. During the floods, one of the middle pillars settled causing a deflection of about 100mm in the middle of the deck. The initial plan was to strengthen or replace the footings and the soil underneath the middle pillars and elevate the middle pillars and the deck. However, after monitoring the bridge for a period of time, a site meeting was held during which the bridge structure was deemed stable and it was decided to elevate the bridge deck back to the position using hydraulic jacks and place elastomeric bearing pads underneath to hold the deck in position. The new solution was considerably easier to implement. It did not involve any excavation work on the creek bed and eliminated all the hazards associated with excavation under water as well as the hazards related to the bridge structure collapsing as the result of excavation under its pillars.

As the Project Manager explained:

> "The solution came from the 'safety in design' visits on-site, that's why I like the site visits. … We had the right players on the day. They said the bridge is pretty much stable, so the design solution we had envisaged back here may no longer be relevant given that the conditions have changed, and they said what we want is to bring that bridge deck levelled."

Case Example 3.3 – The OSH impact of interaction with a fire regulator during the construction of a food processing facility

A food processing facility was being constructed. The plant had been partially destroyed by a fire in 2010, resulting in its closure and the loss of 1,700 jobs in the local area. The facility was offered substantial monetary assistance for re-construction and the planning process was fast-tracked. As a consequence of this support, the client decided to re-build the plant and appointed a contractor under a 'design and build' contract to undertake the project.

The client originally requested not to include a sprinkler system in the food processing building as part of the firefighting system. However, after construction work had commenced, a registered building surveyor advised that, if a sprinkler system was not installed, to satisfy the local building regulations a fire-rated wall would have to be incorporated into the building design to reduce the size of the building compartments.

The decision to include a fire wall was consequently made once the primary structure was constructed. As the 'design and build' contractor's project manager commented:

> "We were literally putting up a building when we found that our areas were over what we thought they were. Whereas normally you would be in a conceptual design you would see it and stop and evaluate it, whereas having been committed to a building out there, we had to make the decision [to include a fire wall].

The plan was to erect the fire wall using a 'tilt-up' panel method of construction. However, penetrations would need to be made in the wall to accommodate plant and services and, at that stage, the dimensions and locations of penetrations were not known. As a result of this uncertainty, it was decided to construct the wall using block work to allow for penetrations to be more easily made when the building's equipment and services design was finalised.

The local fire authority also played an important role, as it became apparent that the building design deviated from the specification standards contained in the local building regulations, necessitating approval of the fire wall design by the fire authority. Notwithstanding a decision to construct the building using fire retardant panels, the fire authority advised that they would not support the original building design because the design did not provide full perimeter access for fire appliances. Once the plant and equipment design was finalised, the design team discovered that the penetrations required in the fire wall were considerably larger than the 600mm² allowed for in the existing block work wall. Not only would this necessitate re-work, but it would also compromise the fire integrity of the wall. Work commenced to enlarge the penetrations, presenting specific OHS risks to workers involved in demolishing sections of the block work wall. Once the plant was installed, the installation contractor then advised that the openings in the block work wall could have been 40% smaller in size.

To maintain the integrity of the firewall, the penetrations were in-filled to the recalculated sizing. However, this reconstruction had to take place after the fixed plant was already installed and workers had restricted access to the work area. The construction of the penetrations required that the block work be cut and flashed with stainless steel in accordance with the food safety regulator's requirements. Whilst the openings were not high in the wall, scaffolding was required to provide access.

The openings in the firewall remained a subject of contention. The fire authority maintained that the block work wall could no longer act as a firewall when it included penetrations. In the opinion of the fire authority, the building was an oversized single building that required a sprinkler system to comply with the building regulations.

An assessment was commissioned from a fire engineer who advised that ‘fire tunnels’ would be required either side of the wall to stop the spread of fire, smoke and heat. The size (or length) of the tunnels was to be proportional to the size of the openings - the larger the opening, the longer the tunnel. However, limited space was available for the construction of fire tunnels as fixed plant had already been installed either side of the fire wall. The original design for the tunnel required a 2.5 metre length, for which there was insufficient space. A reduction in the size of the openings allowed a reduction in tunnel length to 1.8 metres. The construction of the fire tunnel commenced without the fire authority’s approval, in order not to fall behind the project schedule. In the event, the fire authority did not approve this design, insisting on the installation of a full sprinkler system to the building. In order to obtain approval for the building design, the client agreed to retro-fit the building with a sprinkler system after the start-up of production.

The late inclusion of a sprinkler system into the design meant that the installation presented specific OSH challenges as workers needed to negotiate existing plant and services located in the confined space of the ceiling. Another area of OSH concern was access to the underside of the ceiling to install the sprinkler heads. Fixed plant and equipment had been installed in the building, which could not be moved to provide space for access equipment. Further, the production plant was operational when the sprinkler system was installed, providing only a short window of opportunity to carry out the work.

These case studies illustrate the importance of Principle 2, identifying and consulting with all relevant stakeholders in a project when decisions are being made.

3.3 Principle 3: Ensure construction process knowledge is available and used by decision makers

Introduction

Constructors are responsible for the construction operations in a project and thus have a strong motivation and interest in ensuring work can be performed with minimal risk to workers. Compared to other project participants, constructors also have a high level of construction expertise because of their specialized training and knowledge and experience in the application of construction materials and methods. Constructors are therefore able to provide meaningful and important advice about OSH hazards/risks and ways to mitigate them in construction activities. When this information is fed into “upstream” decision-making, i.e., during the planning and design stages of a project, it may be particularly useful.

The principle explained

There is emerging research evidence that design professionals are not always well versed in knowledge of construction methods and/or OSH. Typically design professionals are much more familiar with OSH considerations dealing with the occupation, use and operation of the building/facility. Design professionals are also very knowledgeable and focused on the structural integrity of the building/facility. However, they are less familiar with OSH aspects associated with the manufacture, transport, construction, installation, and commissioning of the building/facility or its component parts. Neither are they always very familiar with OSH issues associated with building/facility maintenance (see Figure 3.3)

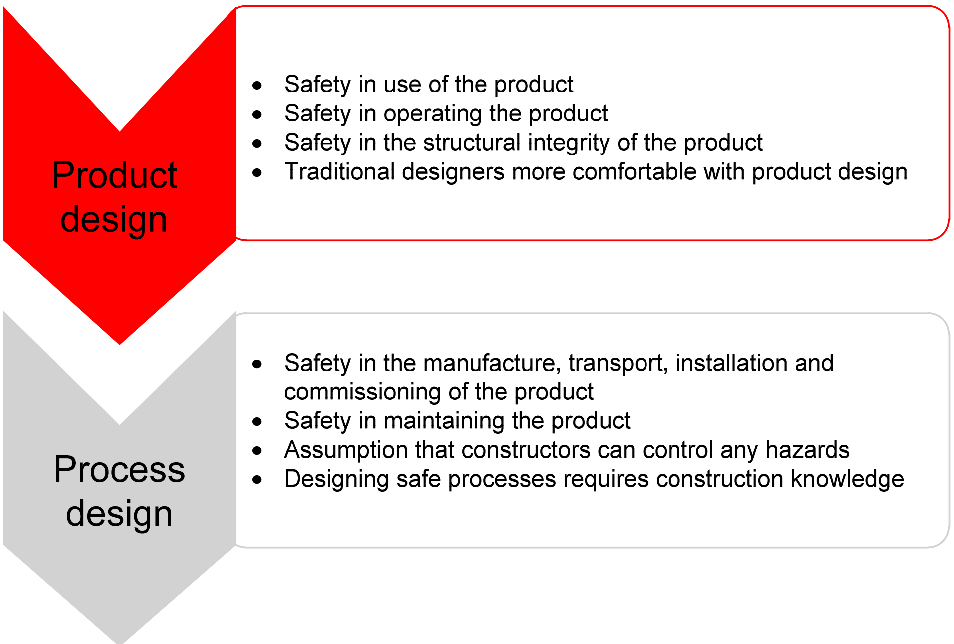

Figure 3.3: Product and process design

It is frequently stated that collaborative or integrated forms of project delivery improve buildability and, by implication, have the potential to also improve OSH. It must be recognized that the procurement method is unlikely, in itself, to create OSH improvement and integrated project delivery approaches do not, therefore, guarantee good project OSH outcomes. However, integrated project delivery mechanisms can create favorable conditions for the consideration of OSH into early project decision-making because they promote increased communication and information exchange between designers, constructors and other project participants.

The research undertaken as part of the international benchmarking study examined the extent to which construction process knowledge was available to decision-makers during the pre-construction stages of 13 Australian case study projects. Social network analysis was used to measure how communication worked between participants in the construction project networks. In particular, communication by the construction contractor was used to measure access to construction process knowledge by decision-makers.

The frequency with which communication flowed from the construction contractor to other parties during the pre-construction stage of the project was measured in each of the 13 project networks. Projects were divided into those which produced higher than average and lower than average OSH performance outcomes (in terms of the implementation of upper level versus lower level risk controls). The results showed a statistically significant difference with better than average OSH risk control outcomes. That is, in projects where more upper level OSH risk control measures were applied, the construction contractor was more engaged in the pre-construction stage. In contrast, projects where the OSH risk controls applied during the construction stage of the project were less effective than average, the construction contractor played a less significant role in project communication in the pre- construction period.[8]

This finding suggests that strategies to elicit constructors' process knowledge during the early stages of a construction project are likely to improve the effectiveness of CHPtD activities and facilitate the adoption of technological/upper level (rather than behavioral/lower level) controls for OSH risk. That is, there is a need to push construction process knowledge upstream to make it available to decision-makers in the design stage of construction projects.

Figure 3.4 illustrates this point conceptually. The red line illustrates the availability of construction process knowledge to decision-makers as the project progresses from design through procurement to construction. As can be seen in the early project stages, the available process knowledge is limited, however construction process knowledge availability increases as the project progresses and increases dramatically at the procurement stage. The red arrow indicates the desired shift to provide greater depth and quality of construction process knowledge to decision-makers earlier in the project life cycle as represented by the red dashed line.

[8] For a full description of these research results see Lingard, H., Pirzadeh, P., Blismas, N., Wakefield, R. & Kleiner, B. (2014). Exploring the link between early constructor involvement in project decision-making and the efficacy of health and safety risk control, *Construction Management and Economics*, 32 (9), pp. 918–931.

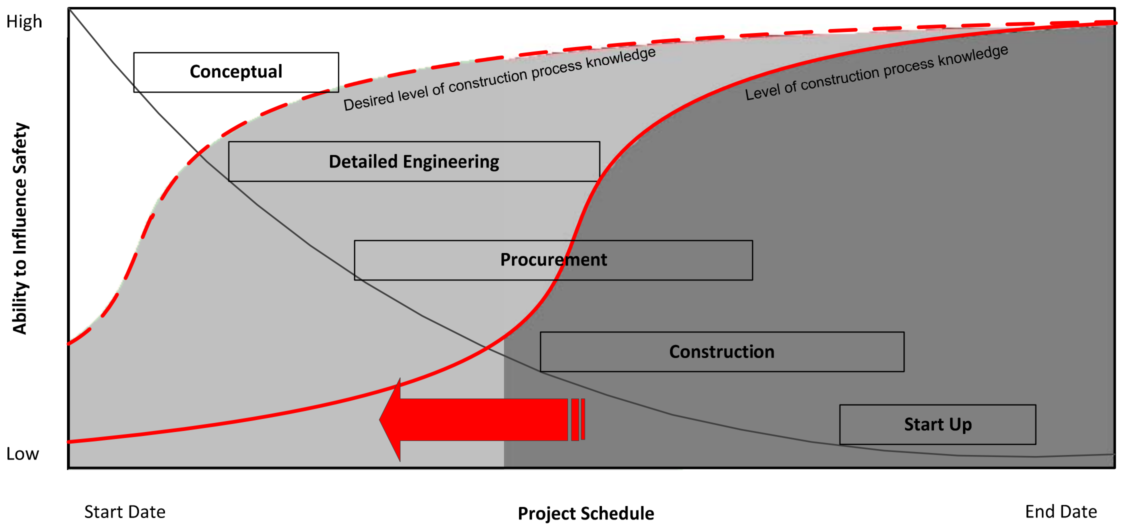

Figure 3.4: Time-process knowledge influence curve [9]

The following examples (3.4 and 3.5) illustrate the application of construction process knowledge by decision-makers early in the construction design stage of projects.

Case Example 3.4 – High rise building façade system

A self-supporting, architectural façade was to be connected to the exterior of a 42-story building. The project used a design and construct delivery method in which the preliminary building design was completed by the client's architects and specialist consultants. The tender documents specified the façade be constructed of a light-weight frame structure made of glass reinforced concrete (GRC) with larger vertical sections made of pre-cast reinforced concrete. During the tender process, the contractor raised concerns about the structural adequacy of the GRC frame for a building of this height. Following the engagement of the design and construction contractor, structural and constructability reviews were conducted to investigate design options and material. A decision was made to use rolled steel sections instead of GRC elements. Consequently, the façade members and connections were re-designed. Using much lighter steel elements reduced material handling and exposure to ergonomic hazards. It also eliminated the risk of the façade structure collapsing during or after construction. The constructor proposed off-site manufacture of the façade. In this way, the construction process would be quicker and eliminating the need to store materials reduced congestion on the small inner-city construction site. The off-site manufacture of the façade reduced exposure to the risk of contact with objects and equipment and reduced the risk of falls, slips, and trips. In the original planned sequence of work, the façade frame was to be fitted off once the building structure was completed. However, the constructor suggested an alternative sequence in which façade elements were to be fitted floor by floor as the building was being vertically

9 Figure adapted from Szymberski, R., (1997), Construction Project Safety Planning, *TAPPI Journal*, 80 (11), pp. 69–74.

constructed. This eliminated the need to work from swing stages or to use other mechanical equipment on the outside of the building. Workers were able to install and connect the framing beams from the safety of a finished floor level.

Case Example 3.5 – Sewerage pumping station

The case involves upgrading a sewerage pumping station to meet the future needs of the local sewerage infrastructure. A substantial amount of the design was completed prior to the tender process. During the feasibility study, it was decided to construct a new wet well (underground storage tank) with increased capacity to replace the existing wet well and to install an extra emergency tank in addition to the two existing tanks on site. New pumps with 55 ltr/s capacity would also be installed, matching the downstream infrastructure capacity. The existing wet well would be retained to maintain the ongoing operations during the construction process.

It was decided that it would be cheaper and easier to have the wet well manufactured off site. However, the design of the tank was not developed with consideration of off-site manufacturing as a construction option. As a result, new moulds needed to be made. Due to the various penetrations in the tank shell, which were determined by interconnecting infrastructure, a number of different moulds were needed as each section of the tank differed.

In addition, no thought was given to the excavation method and the potential issues as a result of the site condition. During excavation, the constructor faced problems with soil instability. To retain the soil, a shielding system was developed consisting of a series of braced steel boxes, approx. 2m in height that could be dropped into the hole, holding the soil back. The shielding system was selected because of the low level of noise that would be produced during installation. However, the removal of the shield after the completion of the construction activities was not considered. Workers experienced difficulties with the removal and the shielding at the bottom of the excavation could not be removed and had to be abandoned in-situ. The contractor was unable to physically remove the shielding due to ground water, which created a suction effect under the shielding.

During the excavation, ground water and sandy soil began to flow back into the excavation through gaps in the retaining shields. To allow work to continue, the constructor had to undertake dewatering of the ditch. This enabled excavation to proceed, however there were difficulties achieving the final depth of 9m due to ingression of water and sand between 7-9 metres. Construction of the tank was brought forward in response to concerns raised by the constructor regarding continued subsidence and the impact it would have on existing infrastructure located in the immediate area as well as the proposed works if left open. To allow further work, the constructor established an exclusion zone that extended approximately 2m around the excavation. Gravel was laid down to the edge of the excavation, creating a safe means of accessing the excavation and installing the tank.

The constructor had assumed that a crane could be used on-site to lift and install the prefabricated tank sections. Once construction started, it became evident that the site was too small for the crane and as such it had to be relocated onto the roadway at the front of the property. OSH risks relating to falling objects, crushing, exposure to electricity and entrapment were now a concern due to movement around power lines, vehicular and pedestrian traffic.

3.4 Principle 4: Implement the hierarchy of controls in decision-making

Introduction

One useful and proven approach to help identify opportunities to improve OSH outcomes and to understand how effectively OSH hazards are being managed is to use the hierarchy of controls (HOC). The HOC arranges OSH control measures in order of their effectiveness. The HOC is based on the principle that making the work environment physically safer and healthier is more effective than changing the behavior of workers.

The HOC is depicted in Figure 3.5. The levels of the HOC are as follows:

- **Elimination**: This is the most effective form of control because the elimination of a hazard poses no risk to the worker or the public. For instance, building roofs at ground level can reduce the hazard of falling from height.
  (If the hazard cannot be eliminated, can the hazard be substituted for something else?)
- **Substitution**: This involves replacing the hazard with a less harmful alternative. For instance, there may be alternative glues or paints that reduce the need for ventilation or personal protective clothing.
  (If the hazard cannot be substituted, can the hazard can be reduced with an engineered control?)
- **Engineering controls**: These isolate or separate people from hazards, such as using screens on high rise construction to remove the hazard of workers falling or tools and materials being dropped.
  (If the hazard cannot be controlled through engineering, can the hazard be controlled or reduced though an administrative process?)
- **Administrative controls**: These include measures designed to change the way workers undertake a task, for example developing safe work procedures or implementing a job rotation scheme to limit exposure, or providing training on specific hazards.
  (If the hazard cannot be controlled through administrative means, can the hazard be controlled or reduced though the worker wearing protective equipment?)
- **Personal Protective Equipment (PPE)**: This is generally regarded as the least effective control measure as it relies on the individual to use it, such as dust masks, ear plugs or fall-protection harnesses. If such controls are not worn or worn properly, they are ineffective. Although, much emphasised and visible on a worksite, PPE should be seen as a "last resort."

The top three layers of control may be classed as technological controls, or "upper level" controls, because they change the physical work environment and materials being used. In contrast, the bottom two elements, "lower level" controls, of the HOC represent behavioral 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.

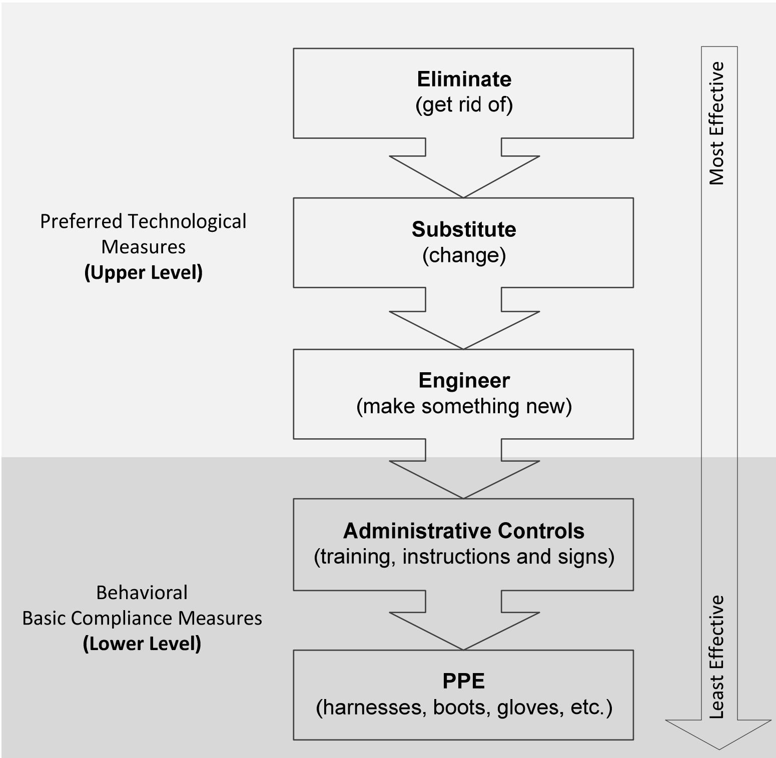

Figure 3.5: Hierarchy of controls

The principle in practice

Example 3.6 (below) shows how, with careful planning and consideration of OSH before construction work starts, hazards can sometimes be totally eliminated. In this case, a change was made to the design of the construction process to eliminate the need for construction workers to work inside a potentially unstable excavation. The change to the construction process was driven by the project management team's desire to ensure the best possible OSH performance on the project. Changing the process necessitated some small changes to the design of the foundation system and the methods used to connect the building's supporting columns, but these changes were minor and resulted in a considerably safer construction method.

Example 3.6 – Elimination of hazardous work inside an excavation

The case study involved the construction of foundations for a food production plant. The project used a design and construct delivery method. The original design of foundation pads involved excavating a 3.5 metre square section of soil to a depth of 700mm, before placing steel reinforcement ready to pour concrete. This activity required construction workers to enter the hole to install the steel reinforcements. The gravelly soil had the potential of becoming unstable and the edges of the excavation could collapse due to the movement of workers in and out of the excavation. To resolve this issue with the original design, the constructor would have needed to over-excavate each area, install the steel reinforcement and formwork and then backfill the area once the concrete pad was poured. The design and construct (D&C) contractor suggested an alternative that involved increasing the size of each pad without installing the steel reinforcements. The excavations needed to be deeper in the alternative design (1.5 metre square by 2 metres deep) but the need for workers to enter the excavation was eliminated. All work could now be performed from ground level.

The site project manager commented:

> "One of the things that I was interested in from a construction point of view is the nature of the soil and the fact that it can crumble away from the edge if you have an excavation open for any length of time. So one of the good design points about the way [the constructor] designed it was the no-reinforcing in the base - it was just mass concrete in the pads under the portals which meant that [the constructor] could dig the hole out with the machine, [connect the] hold-down bolts set up, [and] just backfill straightaway; basically a very quick process so that there'd be less chance of [the edges] frittering away and no need for anybody to be in the hole. So from a safety point of view that was big."

The alternative design also impacted the design of connection bolts to the building's supporting columns. Due to the lack of steel reinforcements, bolts needed to be fixed 'deeper' into the pads (a minimum of 500mm) than would otherwise have been needed. Rather than pouring the pads then drilling the connection bolts, the bolts were cast into the concrete in-situ. Bolts were placed using a jig that spanned the width and extended well past the excavation. The workers could position and fix bolts without entering the excavation.

This design also eliminated the need for the workers to drill through the concrete to the depth required to fit the bolts in the cured concrete. The site project manager explained the process as:

> "…with the holding-down bolts [the constructor] just set up a jig across the top which spanned right out to the safe distance for [the workers] to be able to just take a couple of points on those bolts."

Using the hierarchy of controls to guide decision-making

Figure 3.6 provides a flowchart depicting the recommended process for the selection of controls for OSH hazards and risks.

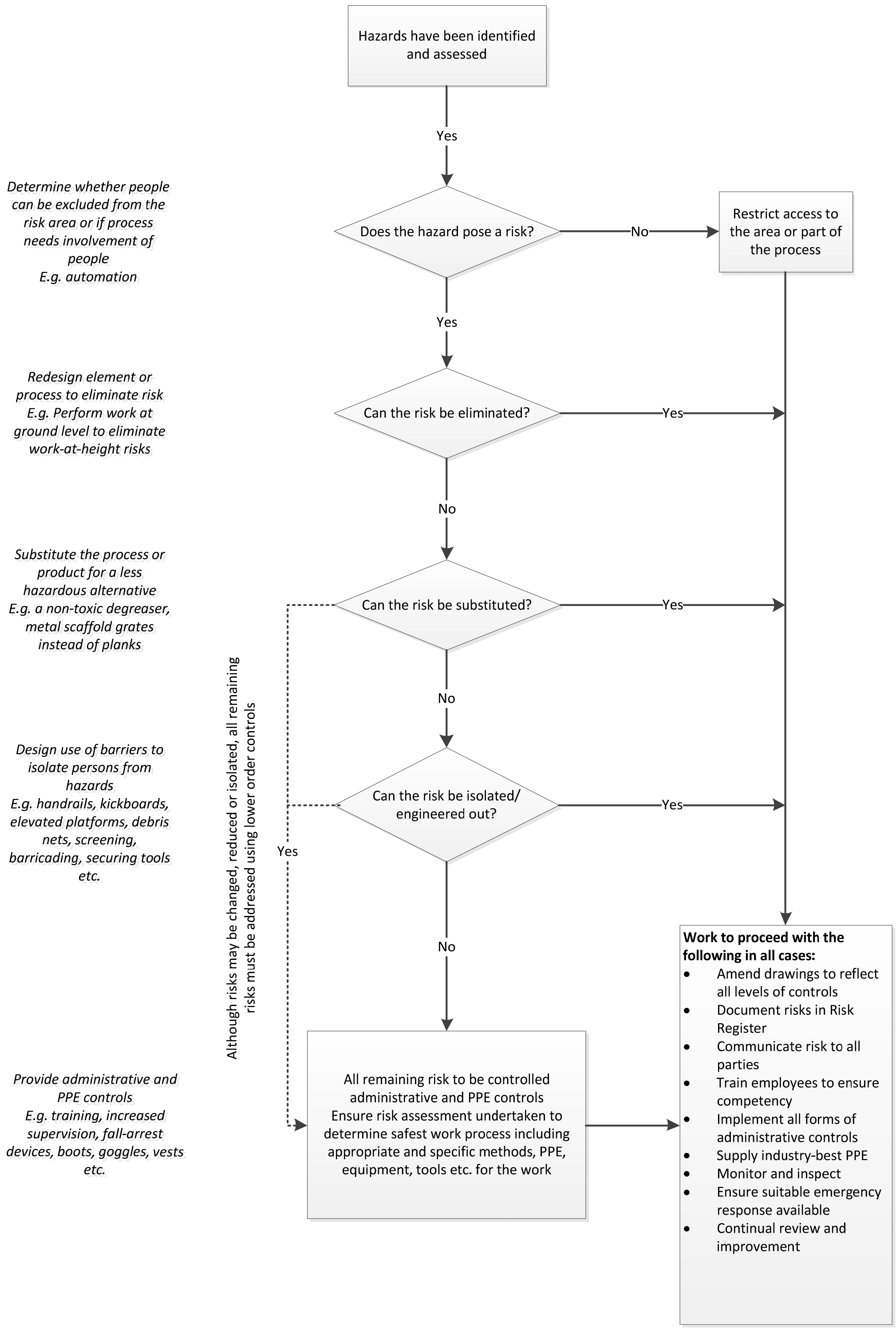

Figure 3.6: The recommended process for the selection of controls for OSH risks

Example 3.7 (below) provides a practical example of how substituting a three column with a two column bridge design significantly reduced OSH risks associated with undertaking construction work adjacent to an operational railway. The replacement of a traditional with a modular column construction method also significantly reduced OSH risks associated with manual handling and the need to work-at-height during the construction of the bridge's supporting columns.

Example 3.7 – Substitution of construction process reduces manual handling and work-at-height risks

The case involved the construction of a pedestrian bridge spanning the railway lines at a new suburban train station. The original concept plan involved the construction of a new 'island' platform, built between two existing and fully functioning rail lines. The footbridge would provide access to the platform from either side of the tracks.

The project used a design and construct delivery method in which the preliminary design was carried out by an engineering consultant engaged directly by the client. The bridge design comprised a walkway which was to be supported by reinforced walls at each end and three columns in-between. As part of the tender submission the design and construct contractor proposed that the number of columns be reduced to two. Eliminating one of the piers would reduce the amount of construction work in the railway corridor (a designated area either side of the tracks). The new design significantly reduced risks associated with train movements and overhead power supply lines. It also increased the separation between construction activities and functioning rail tracks providing more space for crane movement and lifting operations. Furthermore, the bridge foundation did not interfere with the existing tracks and the need for excavation under the train tracks and the risks associated with this activity were eliminated.

The constructor also decided to use a modular design approach to construct the columns in-situ, in three sections. The first section of the column would be built using standard construction methods, whereby formwork and steel reinforcement bars would be installed, the structure propped and the concrete poured. Once the first section was completed it would be used to 'fix and stiffen' the formwork for the next stage. The formwork would be clamped to the completed section and extend up to allow the next three metres of concrete to be poured. This process was repeated until the column reached the required height. By using slip-forms with z-bars to tie the formwork together, the constructor was able to eliminate propping of the top two stages of the column. The requirement for temporary works was significantly reduced. Instead of using scaffolding to allow working at height, the crane was used to help fit and 'slip' the formwork shutters up the columns. This freed up the area from obstacles and falling and trip hazards associated with the temporary works. The only section that needed to be propped was the first stage of the column. Working-at-height issues and manual handling hazards associated with in-situ construction were also considerably reduced through the use of steel reinforcement "cages" that could be fabricated at ground level and lifted into position using a crane.

3.5 Principle 5 – Review and continuously improve performance

Introduction

The construction industry is a dynamic one where work activities and environments can change frequently, often on a daily basis. OSH management needs to be agile to address this but it is important that time and resources are not wasted by applying traditional controls when better ones may be available. This situation is best identified by constantly reviewing control measures to ensure they are doing what was intended. This process is commonly known as continuous improvement and is an important way to keep workplaces safe.

The principle explained

Measuring OSH outcomes

There is a growing recognition that the evaluation of OSH practices should assess the quality and effectiveness of control outcomes.

There is also a growing recognition that using injury or accident statistics to understand OSH performance is not as helpful as it was once thought. Although these types of indicators of OSH performance are easy to measure and to compare between projects and companies, their value is limited because they:

- measure events that are in the past and have gone wrong,
- measure the absence, rather than the presence, of OSH activity,
- are statistically rare and subject to random variation, and
- are subject to high levels of under-reporting and to potential manipulation.

A low accident rate does not guarantee that OSH risks are being controlled or that work-related injuries or diseases will not occur in the future. This is because, although accident rates may be a valid (or true) indicator of past OSH performance, they are less useful in predicting future performance.

Increasingly, construction organizations are moving to the collection and analysis of "leading indicators" of OSH performance. Leading OSH indicators measure safety practices[10] and the effort and strategies employed to improve safety and prevent injury or illness. Examples could include: the number of Prestart or Toolbox discussions, investigation of Near Misses, document reviews with and by work crews onsite, pre-checking plant and equipment, and many more.

There are two important advantages in using leading OSH indicators. Firstly, they provide a more direct measure of how well an organization is managing OSH, and secondly, they provide a quick feedback mechanism, enabling organizations to improve their OSH management processes.

[10] NORA Construction Sector Strategic Goals. At: http://www.cdc.gov/niosh/programs/const/noragoals/projects/00000009.html

One useful leading indicator of OSH performance is the quality of OSH controls that are implemented on a construction project. Projects that use predominantly upper level ways to control OSH risks (i.e., elimination, substitution or engineering) could be said to perform much more effectively than projects where the majority of OSH risk controls implemented are lower level and behavioral (i.e., administration or personal protective equipment).

Part 4 includes a tool to help construction project decision-makers evaluate the effectiveness of OSH risk control outcomes. The tool provides a step-by-step process for generating a quantitative performance score based around the HOC. The tool can be used in two ways:

- during design and construction planning activities to evaluate the OSH performance of different design solutions or choices of construction methods. Used in this way, the tool can help decision-makers to compare risk control implications and select the best possible OSH options.
- during the construction project phase to analyse and evaluate project performance and to inform reflection, learning and continuous OSH improvement.

Part 4: Tools

4.1 Hierarchy of Controls Evaluation Tool

The hierarchy of controls (HOC) is a proven process for identifying the most effective level of control for workplace hazards. The following tool formalizes the HOC by adding a numerical process that allows for easy comparison of the control methods chosen and an easier explanation of hazard control options.

Process for classifying OSH risk controls based on their effectiveness

The process recommended for using the HOC to evaluate and improve OSH outcomes consists of five steps:

- identify the “Feature of Work”,
- identify construction activities and tasks with OSH implications,
- categorize hazards associated with the construction activities,
- identify the control options for each of the hazards, and
- classify and score the safety controls using the HOC.

Step 1: Identifying the “Feature of Work”

Construction projects can be divided into “features of work”[11]. A feature of work is a group of activities which are distinct from other activities in terms of control requirements, location, work crews or disciplines. Depending on the nature of the project and the purpose of OSH evaluation, the definition of features of work can be based on structural elements (e.g. placing cast-in-place concrete foundation, erection of steel columns) or based on work breakdown structure (WBS) items or work packages (e.g. pipe works, roof framing, HVAC) or based on project schedule (e.g. erecting first floor steel framing, second floor overhead piping and electrical). A feature of work should be defined narrowly enough to ensure adequate identification of OSH hazards and controls, yet not be so narrow that it overlooks hazards not readily apparent.

11 The term is based on 'Defined Features Of Work' (DFOW) which is a terminology used by the US Army Corp of Engineers (USACE) and Naval Facilities Engineering Command (NAVFAC).

Step 2: Identify construction activities and tasks with OSH implications

Each feature of work is broken down to identify the construction activities, tasks and significant OSH hazards.

This identification process should include people with appropriate construction experience and knowledge of construction processes and OSH. The differing perceptions of stakeholders need to be considered when working towards consensus in this process.

Step 3: Categorize hazards associated with the construction activities

Construction hazards are categorized according to their type (e.g., fall, slip, trip; struck by object or equipment, etc.).

An OSH risk categorization scheme, such as the National Institute for Occupational Safety and Health (NIOSH) Occupational Injury & Illness Classification System (OIICS)[12], can be used in this step.

Step 4: Identify the control options for each of the hazards

Identify ways to control the OSH posed by each hazard. An example of risk controls for working at height is provided in Table 4.1. The list of control measures noted here should be seen as suggestions only.

12 Bureau of Labor Statistics (2012), Occupational Injury and Illness Classification Manual, at: http://www.bls.gov/iif/oiics_manual_2010.pdf

Table 4.1: Example of risk controls for working at height

Risk Control Category/score	Control Measures
Eliminate the hazard (5)	Structures should be constructed at ground level and lifted into position by crane (e.g. prefabrication of roofs or sections of roofs). Roof penetration should be avoided where possible to eliminate waterproofing activities at height.
Substitute the hazard (4)	Non-fragile roofing materials should be selected. Fragile roofing material (and skylights) should be strengthened by increasing their thickness or changing their composition.
Engineering controls (3)	Permanent walkways, platforms and traveling gantries should be provided across fragile roofs. Permanent edge protection (like guard rails or parapet walls) should be installed on flat roofs. Fixed rails should be provided on maintenance walkways. Stairways and floors should be erected early in construction process so that safe access to heights is provided. Railings and/or screens guarding openings in roofs should be installed before roofing work commences. Temporary edge protection should be provided for high roofs. Guard rails and toe-boards should be installed on all open sides and ends of platforms. Fixed covers, catch platforms and safety nets should be provided. Safety mesh should be installed under skylights and roofs.

Administrative controls (2)	Only scaffolding that conforms to standards should be used. Employers should use equipment that is appropriate to the risk - like elevated work platforms, scaffolds, ladders of the right strength and height, and ensure that inappropriate or faulty equipment is not used. Access equipment should be recorded in a register, marked clearly for identification, inspected regularly and maintained as necessary Access and fall protection equipment such as scaffolds, safety nets, mesh etc. should be erected and installed by trained and competent workers. Working in high wind or rainy conditions should be avoided. Employers should ensure regular inspections and maintenance of scaffolding and other access equipment, like ladders and aerial lifts. Employers should ensure that scheduled and unscheduled safety inspections take place and enforce the use of safe work procedures. Employees should be adequately supervised. New employees should be particularly closely supervised. Employees should be provided with training and information about the risks involved in their work. Employers should develop, implement and enforce a comprehensive falls safety program and provide training targeting fall hazards. Warning signs should be provided on fragile roofs. Ladders should be placed and anchored correctly. Only competent and/or licensed workers should be employed.
Personal protective equipment (1)	Employees exposed to a fall hazard should be provided with appropriate fall arrest equipment such as parachute harnesses, lanyards, static lines, inertia reels or rope grab devices. Fall arrest systems should be appropriately designed by a competent person. Employees should be trained in the correct use and inspection of PPE provided to them. Employees should be provided with suitable footwear (rubber soled), comfortable clothing and eye protection (for example, sunglasses to reduce glare).

Step 5: Classify and score the safety controls using the HOC

Score the selected or implemented risk controls according to the level of the HOC that they represent. Each control is given a score ranging from one (personal protective equipment) to five (elimination) on a five-point scale. In the event that no controls are planned or implemented, a value of zero is assigned.

Using this process can generate an average HOC score for a particular feature of work. Thus, if two hazards are identified and one was eliminated and the other controlled by administrative methods, the average score would be 3.5. The average HOC score reflects the quality and effectiveness of risk control solutions implemented for this feature of work.

The following examples (4.1 and 4.2) and tables (4.2 and 4.3) illustrate this evaluation process in relation to a high rise building façade and the upgrading of a sewerage treatment facility.

Worked example 4.1 – Assessing the quality of risk controls for construction of a high rise building façade system

The project used a design and construct delivery method in which the preliminary building design was completed by the client's architects and specialist consultants. The tender documents specified the building façade to be constructed of a light-weight frame structure made of glass reinforced concrete (GRC) with larger vertical sections made of pre-cast reinforced concrete. During the tender process, the contractor raised concerns about the structural inadequacy of the GRC frame for a building of this height.

Following the engagement of the design and construct contractor, structural and constructability reviews were conducted to investigate design options and materials. A decision was made to use rolled steel sections instead of GRC elements. Consequently, the façade members and connections were re-designed. By using much lighter steel elements, material handling and exposure to ergonomic hazards were reduced. It also eliminated the risk of the façade structure collapsing during or after construction.

The constructor also proposed off-site manufacture of the façade. In this way, the construction process would be quicker. The need to store materials would also be eliminated and congestion on the small inner city site would be reduced. The off-site manufacture of the façade reduced exposure to the risk of contact with objects and equipment and reduced the risk of falls, slips, and trips.

In the original planned sequence of work, the façade frame was to be fitted-off once the building structure was completed. However, the constructor suggested an alternative sequence in which façade elements were to be fitted floor by floor as the building was being vertically constructed. This eliminated the need to work from swing stages or other mechanical equipment on the outside of the building. Workers were able to install and connect the framing beams from the finished floor levels in a safer manner.

Table 4.2: Assessing the quality of risk controls for construction of a high rise building façade system

Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Material handling and construction activities for the WRAP façade	Installation of horizontal frame elements for the façade structure	Overexertion in holding, carrying, or wielding Struck, caught, or crushed in collapsing structure, equipment, or material	Using light-weight material to build frame elements	Substitution	4	4.07
Installation of frame elements for the WRAP structure (façade)	Connecting the frame elements back to the slab	Overexertion bending, crawling, reaching, twisting, climbing, stepping	Using rolled steel in place of GRC and reducing the number of connections required	Substitution	4	
Building WRAP frame elements	Building façade frame elements from rolled steel folded into rectangular shape	Contact with objects and equipment Overexertion in holding, carrying, or wielding	Off-site manufacturing	Elimination	5	
Installation of steel elements	Lifting large sections to position using crane	Struck by object or equipment	Training, safe work method statement, work sequence	Administrative	2	
Installation of façade frame	Positioning and connecting frame elements to each other and to the slab	Falls to lower level	Installing the façade elements floor by floor, accessing the work area from finished floors	Elimination	5	
Installation of façade frame	Installation of façade frame elements at each floor without permanent exterior walls	Falls to lower level	Protection by safety screens	Engineering Control	3	
Installation of façade frame elements	Connecting the intersecting elements together	Overexertion bending, crawling, reaching, twisting, climbing, stepping	Fabricating the intersecting sections as a single section off site to reduce the number of connections	Substitution	4	
Fixing façade frame to the slab	Connecting the frame back to the slab to fix the façade	Contact with objects and equipment	Cast ferrules into the precast slab to eliminate the need for drilling into the concrete	Elimination	5	
Beam connections	Connecting the beams to the intersecting sections using connection arms	Overexertion bending, crawling, reaching, twisting, climbing, stepping	Attaching connection arms to the beams in factory to eliminate the need to weld or bolt the connection arms on site	Elimination	5	

Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Frame connections	Connectors between frame and cast -in ferrules	Overexertion bending, crawling, reaching, twisting, climbing, stepping	Using connectors providing 20 mm tolerance in all directions to provide some flexibility during installation	Substitution	4	
Beam connections	Installing and tightening bolts on connection plates inside the beams	Overexertion bending, crawling, reaching, twisting, climbing, stepping	Increasing the size of the panel openings to have more space and better access to the connection area	Substitution	4	
Beam connections	Installing and tightening bolts on connection plates inside the beams	Falls to lower level	Access to all connection points specifically located in a position easily reached from the finished concrete floors. The clearance between the façade frame and the building was reduced to allow for frame connection works be undertaken from behind the safety of the perimeter barricading.	Elimination	5	
Vertical frame elements	Temporary works for installation of precast RC vertical elements spanning over 2 floors	Struck, caught, or crushed in collapsing structure, equipment, or material	Propping the vertical elements into position to resist wind and lateral forces while waiting for the next floor slab to be ready to continue installation	Engineering Control	3	
Vertical frame elements and connections	Connection between vertical elements and crisscross sections on top levels	Contact with objects and equipment	Designing the vertical precast elements to span over 2 floors to reduce the number of connections required as well as the amount of temporary works needed to support the elements	Substitution	4	
Painting the frame	Painting the frame	Falls to lower level	Painting the elements prior to installation, only touch-ups were done on site in case of any damage.	Substitution	4	

Worked example 4.2 – Assessing the quality of risk controls for upgrading a sewerage treatment facility

An existing centrifuge and existing piping were to be upgraded at a sewerage treatment plant. The new equipment was to be connected to existing live piping infrastructure, however to install the equipment a number of existing pipes would need to be removed. As the majority of the pipes were suspended from the ceiling, this work was to be carried out at height using elevated working platforms or scaffolding.

During the design stage it was found that the new centrifuge would need to be placed over a large void cut into a suspended slab. The void provided a connection to the inflow and outflow piping system. The existing centrifuge was larger than its replacement. A structural report confirmed that a bigger centrifuge could be supported on the slab. By identifying this issue at the design stage, the potential amount of re-work required during construction was reduced. Activities such as infilling part of the opening to make it smaller or constructing some type of supporting system to span the void would have increased the amount of construction work and introduced new hazards.

However, during procurement it was discovered that another new centrifuge that had been selected to replace two smaller, substandard pumps, would not meet the capacity requirements stipulated by the client/operator. A larger centrifuge that met all the criteria was subsequently purchased. This centrifuge was to be located on a mezzanine level with an adjoining void equal to the height of a six story building. During the installation of the centrifuge it was identified that, due to its size, full perimeter access around it was not possible, and that a platform would need to be installed. This involved connecting a steel platform to the edge of the concrete mezzanine floor and cantilevering over the void. Installation of the platform would prevent workers from having to lean out over the void to gain access to the end of the centrifuge. While a large portion of the platform was erected off site, access to the edge of the slab was still needed in order to fix the platform into position. A specialist scaffolding contractor was engaged to design and install a temporary cantilever scaffold to address the hazards associated with working from this height. Due to the size and weight of the partially completed platform, a crane was used to move the structure into position, however existing plant and infrastructure in the area severely hampered the crane's movements. Other OSH hazards were also identified with this work including the effects of fumes and gases in carrying out on-site welding.

One of the control strategies to address these risks included the needed to wear PPE. Given that the work was carried out during the summer months and within close proximity to an industrial heater, the use of PPE to mitigate the identified risks produced new hazards, such as heat stress and fatigue. Using the HOC evaluation method, the quality of OSH controls implemented for the above case was measured and the average HOC scores are calculated.

Table 4.3: Assessing the quality of risk controls for upgrading a sewerage treatment facility

Feature of Work	Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Installation of centrifuge	Fitting and installation of the centrifuge over the slab opening	Temporarily suspending the centrifuge over the opening using a crane to modify the supports and fittings, due to difference in size of the new and the old centrifuges	Struck by object or equipment	Changing the centrifuge type to fit over the slab opening	Elimination	5	2.7
			Struck, caught, or crushed in collapsing structure, equipment, or material				
Pipe works	Installation of temporary pipes to connect the centrifuge to the existing infrastructure	Working around existing pipes and structures, carry, lift and connect pipes. Remove and reinstall existing pipes in some cases	Struck by object or equipment	Using safety hats and gloves	PPE	1	
Pipe works	Upgrading the existing piping system	Access to pipes suspended from ceiling	Falls to lower level	Elevated platforms and scaffolding	Engineering Control	3	
Pipe works	Connections	Welded connections	Ignition of clothing from controlled heat source	Using ‘Vitolux’, no need for welding and easy and quick to install	Substitution	4	
			Exposure to harmful substances or environments				
Installation of centrifuge	Access around the centrifuge	Workers lean out over the adjoining void to gain access to end of the centrifuge	Falls to lower level	Installation of a steel platform to the edge of the concrete slab cantilevering over the void	Engineering Control	3	
			Overexertion bending, crawling, reaching, twisting, climbing, stepping				
Construction/erection of the steel platform	Steel works	Steel works to erect the platform, on-site vs. off-site	Contact with objects and equipment	Off-site manufacturing	Elimination	5	
Installation of the platform	Installation works at height	Installation works at height	Falls to lower level	Temporary cantilever scaffolding	Engineering Control	3	

Feature of Work	Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Installation of the platform	Lifting	Lifting the prefabricated platform into position using a crane, close to existing infrastructure	Struck, caught, or crushed in collapsing structure, equipment, or material	Safe work method statements, job training, work sequencing	Administrative	2	
Installation of the platform	Welding	On-site welding to install platform	Ignition of clothing from controlled heat source	Using protective equipment	PPE	1	
			Exposure to harmful substances or environments	Using protective equipment	PPE	1	
Installation of the platform	Working in summer close to an industrial heater	Working in summer close to an industrial heater and wearing PPE	Exposure to temperature extremes	Induction, job rotation	Administrative	2	
			Overexertion and bodily reaction	Induction, job rotation	Administrative	2	

Using HOC evaluation tool for comparison and benchmarking

The average HOC score indicates the quality of risk control solutions implemented for that feature of work. These scores can be a useful and quick way of assessing the benefit of one control approach compared to another but as the score is a collective one across all HOC categories, additional analysis of the scores is recommended.

One method is to look at the distribution of the HOC scores for the OSH risk controls for each feature of work. This can be done by counting the number of risk controls under each HOC category (Elimination to PPE) and developing a bar graph for each feature of work. The horizontal axis of the bar graph shows the five HOC categories and the vertical axis represents the frequency count of the implemented OSH risk control category.

This can be particularly useful for design professionals to visualize the spread of the OSH risk control solutions in terms of their effectiveness. By mapping the implemented OSH risk control solutions before and after design changes, design professionals can evaluate the effectiveness of these changes for controlling OSH risks.

The method can also be used to help to decide on, change, and improve OSH risk control solutions at early stages of projects, monitor and review them during the design development, and communicate them with other stakeholders.

The following Example 4.3 indicates the application of the tool to evaluate the effectiveness of proposed design changes to control OSH risks during excavation work.

Case Example 4.3 – Assessing the quality of OSH risk controls for excavation activities in the construction of a basement mausoleum

A basement mausoleum was to be constructed in a cemetery. The site was surrounded by existing graves and established trees planted among them. To maximize the usable area the client proposed a setback of just over two meters from the adjoining grave sites and trees.

The temporary works design required that a retaining wall and bored concrete piles be constructed, at 1800mm centers, around the perimeter of the excavation to retain the soil. External propping using ground anchors was then to be installed to prevent rotation of the wall. The exposed soil between the piles would then be retained using shotcrete. Once the temporary works were completed construction of the permanent works could commence from the bottom up.

However, once engaged, the constructor proposed a safer 'top down' approach in which the construction of a retaining system would start at ground level and progressively work its way down as excavation continued in stages until the required depth was reached. The constructor also proposed eliminating the rock anchors due to a number of risks associated with them. To ensure that the anchors posed no threat to any construction activities that may occur next to the mausoleum in the future, the ground anchors would need to be de-stressed. Gaining access to the anchors to de-stress in the original design would require the constructor to enter the 'gap' between the temporary wall and the mausoleum wall, remove the anchor's cap and then de-stress or cut the steel rods in a small, confined space. This would create ergonomic hazards for workers having to maneuver within a confined space. The potential for the stressed bars to react when released and hit the workers created extra OSH risk.

The internal propping required for the system had to be designed to provide enough clearance for the machinery to move safely around without the danger of running into and knocking over props. To achieve this, the constructor proposed to use "Megaprops". Unlike alternative internal propping systems that connect to the face of the wall and are anchored back down into the bottom of the excavation, taking up a lot of valuable space, "Megaprops" are large steel beams installed at the top of the excavation and span the width of the excavation, pushing back against opposing walls. This requires fewer props to be installed and frees up the base of the excavation so that a clear and unobstructed area is available to undertake excavation.

For ease of installation, the connection brackets were cast on to the top of the ring beam rather than on the walls. This eliminated the need to drill into the concrete at a later stage to secure the props. To assist with the "Megaprop" installation each connection plate was made with a 'lip' that provided temporary support to the props once they were lowered onto the connection plate. The connection bolts could then easily be threaded through the prop and into the connection plate without the need for a crane to hold it in position until such time as the prop was fixed at both ends. All fixing could be done at ground level due to the connections being located on the top of the capping beam. Table 4.4 shows the application of the HOC evaluation method to the mausoleum case study. The average HOC score is calculated and only tasks related to the excavation of the basement are included.

The following Table 4.4 compares the effectiveness of OSH risk controls before and after the changes proposed by the constructor.

Table 4.4: Evaluation of OSH risk controls for excavation of basement activities

Task	Hazard	Original Design solution	Original HOC Level & Score	Average HOC Score	Revised Design/OSH Intervention	Revised OSH Control Level & Score	Average HOC Score
Excavation using small machinery	Struck by object or equipment	Establishing exclusion zones, appointing spotters	Administrative (**2**)	**2.13**	-	-	**4.25**
Deep excavation (8.5 m)	Caught in or compressed by equipment or objects	Temporary works to retain the soil	Engineering control (**3**)		-	-	
Installation of temporary works in the excavation ditch	Caught in or compressed by equipment or objects	Bored concrete piles, propping, shotcrete (trained workers working in the excavation ditch)	Administrative (**2**)		Top-down excavation and installing temporary works simultaneously, No temporary work after excavation	Elimination (**5**)	
Temporary works, Propping inside the excavation ditch	Struck, caught, or crushed in collapsing structure, equipment, or material	Trained workers enter the excavation ditch and install props	Administrative (**2**)		Installing “Megaprops”, No need to enter the ditch, Workers to install “Megaprops” from ground level	Substitution (**4**)	
Excavation using machinery	Caught or compressed by collapsing material	Machinery working close to props, appointing spotters to avoid hitting props	Administrative (**2**)		Using “Megaprops”, No need for props in the excavation ditch	Elimination (**5**)	
De-stressing the rock anchors	Struck by object or equipment	Trained workers remove the anchor’s cap and then de-stress or cut the steel rods	Administrative (**2**)		Using “Megaprops”, No need for rock anchors	Elimination (**5**)	
De-stressing the rock anchors	Working in a confined space	Trained workers enter the ‘gap’ between the temporary wall and the mausoleum wall	Administrative (**2**)		Using “Megaprops”, No need for rock anchors	Elimination (**5**)	
Temporary works, Installing “Megaprops”	Fall from height Overexertion in holding, carrying, or wielding	Form work around the brackets as well as sealing	Administrative (**2**)		Cast brackets on to the top of the capping beam no need for installation	Elimination (**5**)	

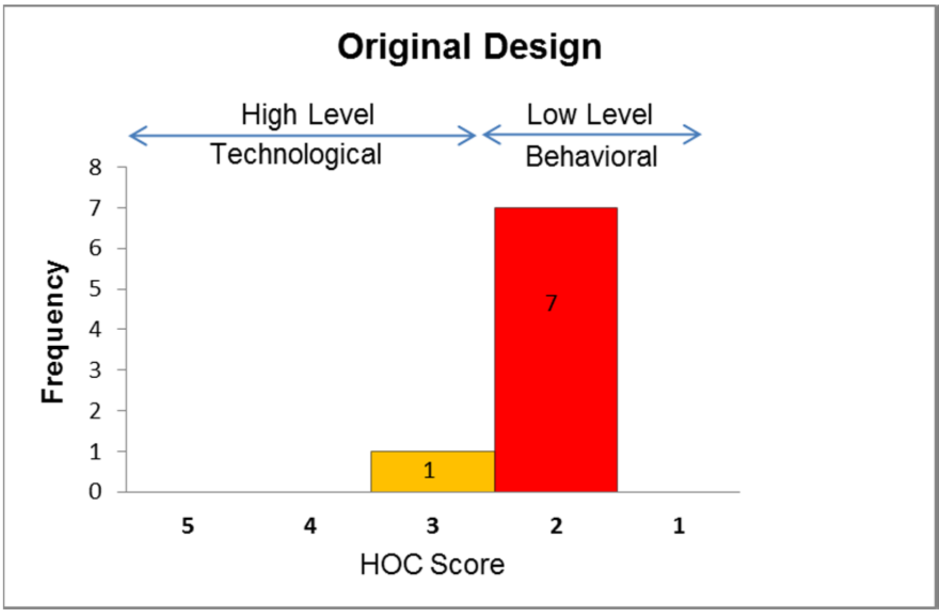

Figure 4.1: Distribution of OSH outcomes before the design change

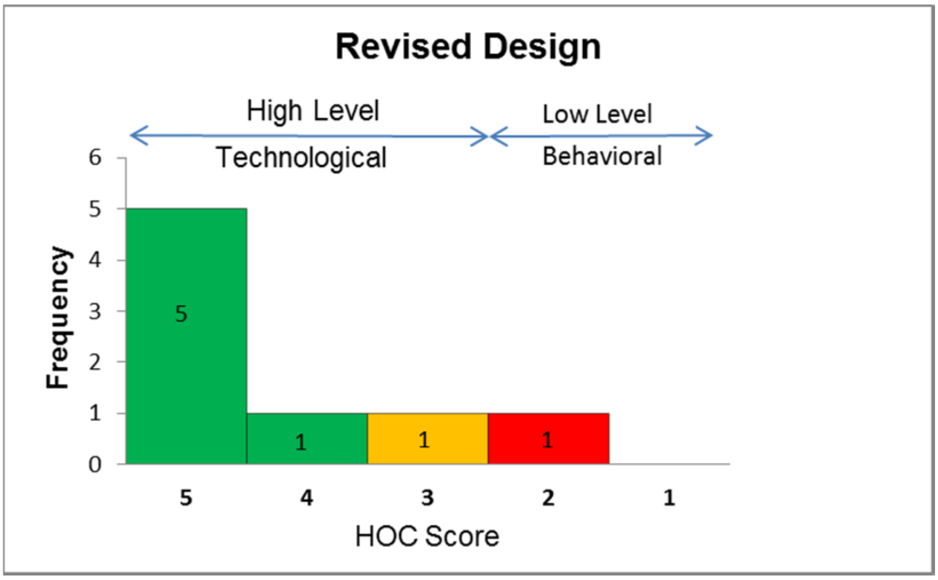

Figure 4.2: Distribution of OSH outcomes after the design change

Figure 4.1 shows the OSH risk control distribution associated with the original design solution while Figure 4.2 shows the risk control distribution after the design was revised. As the bar graphs show, the original design relied on workers' behavior and on-site controls (lower-level controls) to address OSH risk with the majority of the OSH risk controls (87%) being behavioral/lower level controls. As a result, the original design has a low average HOC score (2.13).

Changing the design of a feature of work can have a substantial impact, improving the quality of OSH controls realized, as shown in the change in scores from 2.13 to 4.25.

The advantage of using the HOC method is that the distribution of risk controls can be analyzed, understood and reviewed when design decisions are made. Thus the HOC Evaluation Tool can help compare different design options in terms of the quality and effectiveness of their OSH outcomes and identify the features of work with lower level controls, so interventions to improve these risk controls can be implemented.

In a similar way, the HOC evaluation tool can be used for comparing and benchmarking projects or features of work in terms of the extent and effectiveness of the implemented OSH risk controls. The following example (4.4) shows this application.

Work example 4.4 – Assessing the quality of risk controls for construction of a food processing plant

The project involved the construction of a food processing plant and associated storage facilities on a greenfield site. A concept design was developed at the early stages of the project. The concept design included a steel framed structure consisting of three spine trusses supported by five rows of steel columns. To maximize useable floor space, the columns were positioned in the middle of product stacks rather than at the ends of the rows. A design and construct delivery method was chosen by the client to allow the contractor to use their experience and knowledge of construction technology and methods to enhance constructability and safety.

During the design stage, the contractor proposed eliminating one row of columns. This design alternative required fewer columns to be lifted and maneuvered into place, reducing the duration of exposure to OSH risks associated with lifting operations. The contractor also suggested the use of trussed rafters connecting to the main spine trusses instead of using steel beams as rafters. The fabrication of trusses was slightly more expensive, but these trusses weighed less than steel beams and could be manufactured off-site. The reduced weight of the roof enabled the use of smaller sections for supporting columns. It also made the erection and installation of the roof quicker and easier. All the columns were fitted with a bearing plate allowing trusses to be temporarily supported while connections at each end were bolted. This reduced the need for propping and freed the area around the columns and under the trusses of any obstacles.

At the same time, this design solution reduced the extent of work required at height to connect the trusses to the columns. The structure was designed so that erection could be done in self-supporting sections. The constructor could start the installation at one end of the building and move progressively along the length of the building and ensure that crane lifts were within safe reach tolerances.

The roof cladding included fiberglass sheeting at regular intervals across the roof to act as skylights. Having to install skylights in the roof meant that the constructor would be working in an area with open sections of roofing. To overcome the issue of falls from height, safety mesh was installed on the underside of the roof frame. The constructor developed a sequence of work which involved laying steel sheets while leaving gaps where the fiberglass sheeting was to be installed rather than laying all the steel cladding and then cutting/removing sections to create skylight openings. This made the adjustment of fiberglass sheets much easier and reduced the amount of work at height as well as manual handling required for installation of the sheets.

The foundations were designed without any steel reinforcement. The excavation could be performed from ground level using excavators and the need for workers to enter the excavation was eliminated. Due to the lack of steel reinforcement, bolts needed to be fixed 'deeper' into the pads (a minimum of 500mm). Rather than pour the pads then drill the connection bolts, the bolts were cast into the concrete in-situ. Bolts were placed using a jig that spanned the width and extended well past the excavation. The workers could position and fix bolts without entering the excavation. This design also eliminated the need for the workers to drill through the concrete to the depth required to fit the bolts in the cured concrete.

The OSH risks and the controls implemented for each feature of work are summarized in the following tables and are classified based on their effectiveness using the HOC process. The HOC scores are then used to calculate the average HOC score for each feature of work. Moreover, a bar graph is created for each feature of work to indicate the distribution of OSH risk controls based on their effectiveness. In this way, the effectiveness of OSH solutions for the three features of work can be compared.

Table 4.5: Assessing the quality of risk controls for the erection of a roof system during construction of a food processing plant

Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Construction of the main roof trusses	Cutting, welding and bolting steel sections to build main spine trusses	Overexertion and bodily reaction	Off-site manufacturing of trusses	Elimination	5	3.83
Construction of the main roof trusses	Welding steel elements to build main spine trusses	Exposure to electricity	Off-site manufacturing of trusses	Elimination	5	
Construction of the main roof trusses	Connecting steel elements at height	Fall, Slip, Trip	Off-site manufacturing of trusses	Elimination	5	
Construction of the main roof trusses	Lifting steel elements to position	Struck by object or equipment	Off-site manufacturing of trusses	Elimination	5	
Installation of roof structure	Ensuring the stability of the structure during 'temporary' construction loading conditions	Struck, caught, or crushed in collapsing structure, equipment, or material	Adding construction sequence schedule to structural drawings, considering temporary construction loads in structural design	Substitution	4	
Installation of the roof main spine trusses and rafters	Access to the work area to put in place the roof main trusses and rafters	Struck by object or equipment	sequence of work using computer modeling to ensure constructability and safe erection	Administrative	2	
Installation of roof rafters	Lifting roof rafters which connect off the main spine trusses using crane	Struck by object or equipment	Using trussed rafters which are lighter than I beams	Substitution	4	
Installation of roof rafters	Connecting trussed rafters to the columns	Struck by object or equipment	Installing bearing plates on columns to temporarily support rafters during installation	Elimination	5	
Installation of roof rafters	Connecting trussed rafters to the columns	Struck, caught, or crushed in collapsing structure, equipment, or material	Installing bearing plates on columns to temporarily support rafters during installation	Elimination	5	

Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Trussed rafters	Fabrication of trussed rafters	Overexertion in holding, carrying, or wielding	Prefabrication of trussed rafters	Elimination	5	
Propping work	Installation of props to hold rafters in position during erection of the roof structure	Overexertion in holding, carrying, or wielding	Installing bearing plates on columns to temporarily support rafters during installation, minimized propping work	Substitution	4	
Assembling of spine trusses	Connecting together prefabricated sections of spine trusses in each span using bolts	Falls to lower level	Connecting the sections on the ground before lifting	Substitution	4	
Installation of spine trusses	Elevating span-wide truss sections in position, and making connections	Struck by object or equipment	Designing the truss spans to extend beyond the next supporting column to provide a temporary support for the next truss section	Elimination	5	
Access to the roof	General	Falls to lower level	Using ladders and PPE	PPE	1	
Installation of roof cladding	Installation of roof panels/sheets on roof structure	Falls to lower level	installing safety mesh around the roof	Engineering Control	3	
Installation of skylights on the roof	Cutting roof cladding, installation of fiberglass sheet panels in open sections of roof	Overexertion bending, crawling, reaching, twisting, climbing, stepping	Changing work sequence, Leaving gaps in the roof cladding while installing iron sheets to install skylights later and avoid rework	Administrative	2	
Installation of skylights on the roof	Cutting roof cladding on the roof, installation of fiberglass sheet panels in open sections of roof at height	Fall, slip, trip	installing safety mesh around the roof	Engineering Control	3	
Changing the location of openings and services on the concrete panels	Cutting through the concrete panels to change the location of openings and services	Repetitive motions	Using heavy machinery for lifting and cutting, job rotation	Administrative	2	

Table 4.6: Assessing the quality of risk controls for the erection of steel columns during construction of a food processing plant

Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Erecting steel columns	Maintain access around the work area	Struck by object or equipment	sequence of work using computer modeling to ensure constructability and safe erection	Administrative	2	3
Erecting steel columns	Ensuring the stability of the structure during 'temporary' construction loading conditions	Struck, caught, or crushed in collapsing structure, equipment, or material	Structural design account for construction sequencing, adding construction sequence schedule to structural drawings, considering temporary construction loads in structural design, structural engineer undertake periodic inspections throughout construction	Substitution	4	
Erecting steel columns	Lifting steel columns using crane and maneuver into position	Struck by object or equipment	Reducing the number of columns (eliminating an entire row of columns in the design)	Substitution	4	
Erecting steel columns	Lifting/erecting steel sections in position and connecting them together	Struck, caught, or crushed in collapsing structure, equipment, or material	Designing the sections to be self-supporting during erection, starting erection at one end of the structure and moving progressively to the other end	Substitution	4	
Erecting steel columns	Welding steel section	Exposure to electricity	Using PPE, stop working during wet weather	Administrative	2	
Erecting steel sections	Erecting the steel sections/general work	Struck, caught, or crushed in collapsing structure, equipment, or material	Propping the temporary structures as an on-going construction safety procedure due to potential seismic activity in the area	Engineering Control	3	
Erecting steel sections	Unhooking steel members from crane hook at height	Falls to lower level	Using height access equipment, SWMEs and induction	Engineering Control	3	

Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Erecting steel sections	Lifting steel members using mobile cranes	Struck by object or equipment	Mobile Crane Induction for personnel and operators, Ensuring crane is fit to purpose, Inspecting chains/slings prior to use, ensuring adequate ground clearance for loads while in transit	Administrative	2	
Erecting steel sections	Lifting steel members using mobile cranes	Struck, caught, or crushed in collapsing structure, equipment, or material	Ensuring proper use of crane to avoid crane collapse, Ensuring ground condition and bog mats are suitable and stable, considering and observing lifting limits at all times, monitoring wind condition	Administrative	2	
Erecting steel sections	Propping of temporary structures	Fall, slip, trip	Constructing the structure in self-supporting sections to minimize the amount of temporary propping required, and removing propping after completion of each span	Substitution	4	
Erecting steel sections	Installing safety mesh at height	Falls to lower level	Using height access equipment, PPE	Engineering Control	3	

Table 4.7: Assessing the quality of risk controls for the foundations in the construction of a food processing plant

Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Excavation	Excavation to place pad foundations	Caught in or compressed by equipment or objects	Obtaining final geotechnical report, using machinery for excavation, creating exclusion zones	Administrative	2	3.11
Excavation	Excavate square sections for pad foundations	Falls to lower level	Excavation from ground level using excavator, no need to enter the excavation hole	Substitution	4	
Excavation	Using plant for excavation, mobile plant close to personnel	Struck by object or equipment	Personnel induction, visibility PPE, using licensed operators, signage and exclusion zones	Administrative	2	
Foundation reinforcement	Placing reinforcement steel mesh at the bottom of excavated holes for pad foundations	Struck, caught, or crushed in collapsing structure, equipment, or material	Changing the foundation design (dimensions) to eliminate reinforcement	Elimination	5	
Foundation reinforcement	Placing reinforcement steel mesh at the bottom of excavated holes for pad foundations	Fall, slip, trip	Changing the foundation design (dimensions) to eliminate reinforcement	Elimination	5	
positioning holding down bolts for column base connection	Placing holding down bolts for column base connection in position before casting concrete	Falls to lower level	Using a jig spanning the width of the excavation and extended past the excavation to keep the bolts in position and then casting concrete	Substitution	4	
Pouring concrete	Using concrete pump to pour concrete, high pressure release of concrete	Struck by object or equipment	Developing SWMS, workers induction, PPE, regular testing and cleaning of pumps and lines	Administrative	2	

Activity	Work Task	Safety Challenge	Response to Safety Challenge	HOC Level	HOC Score	HOC Average
Pouring concrete	Using concrete pump to pour concrete, high pressure release of concrete	Exposure to harmful substances or environments	Developing SWMS, workers induction, PPE, regular testing and cleaning of pumps and lines	Administrative	2	
Pouring concrete	Using concrete pump to pour concrete, high pressure release of concrete, holding and maneuvering the concrete line	Overexertion and bodily reaction	Developing SWMS, workers induction, PPE	Administrative	2	

Figures 4.3 – 4.5 (below) indicate the roof structure is the feature of work with the most implemented risk controls, with the majority of controls being upper level, technological controls.

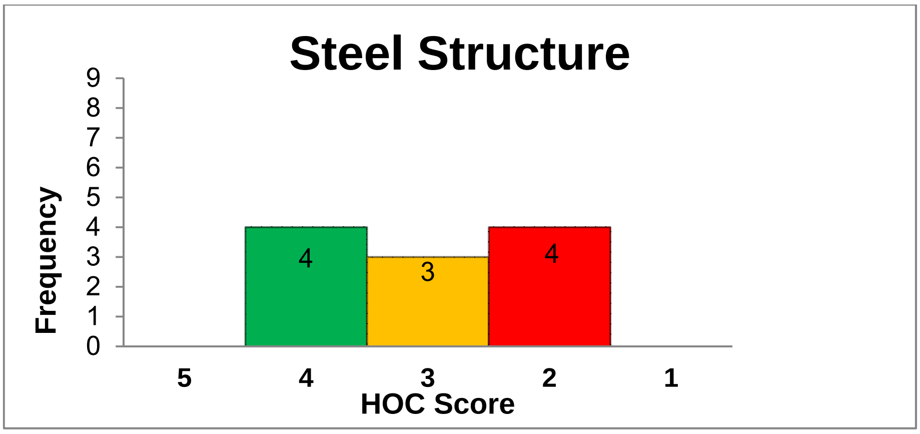

Figure 4.3: Distribution of OSH risk controls for the Steel Structure

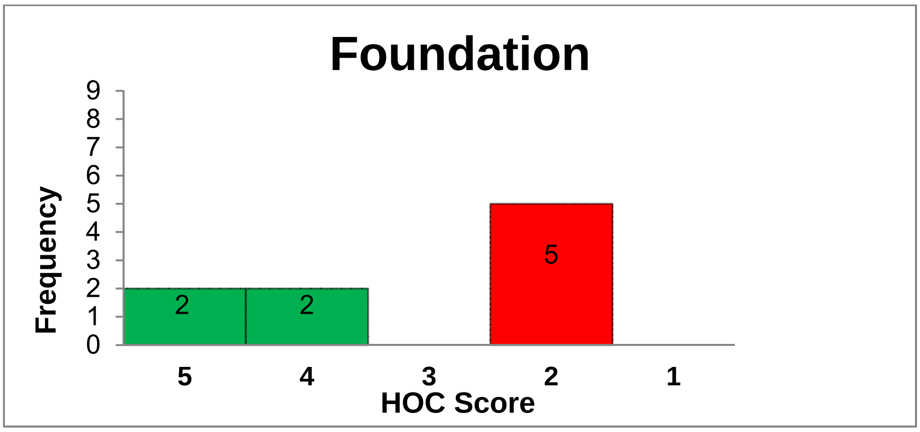

Figure 4.4: Distribution of OSH risk controls for the Foundation

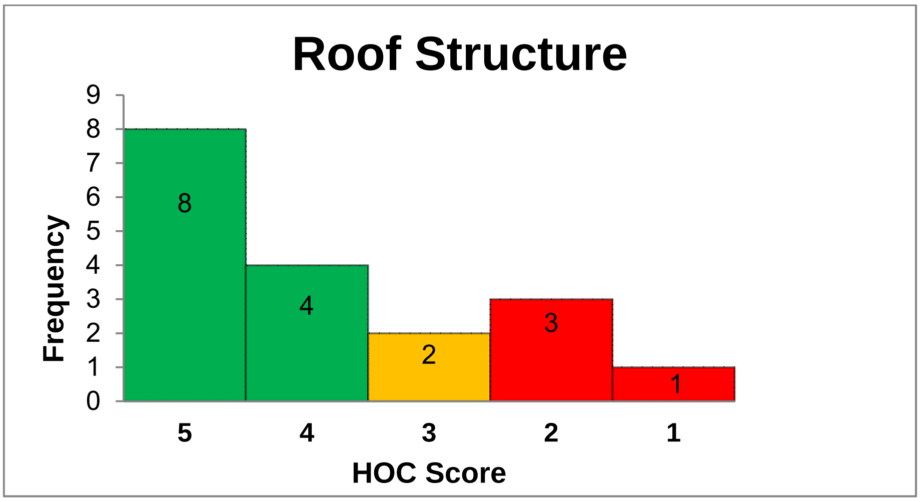

Figure 4.5: Distribution of OSH risk controls for the Roof Structure

When comparing the steel structure and the foundation, both cases are almost similar in the number of identified risk controls (eleven and nine respectively). The foundation has a higher average HOC score suggesting that the controls implemented were more effective. However the bar graphs show that in the construction of the steel structure, the majority of the controls are upper level risk controls (64%), while in the case of foundation, the majority of the controls are behavioral based/lower level controls, with only 44% of the controls being scored above 3. In other words, although the average HOC score for the foundation is higher, the application of upper level controls for the steel structure may be considered to be more effective.

So what does this all mean?

The hierarchy of controls (HOC) provides a framework for the elimination or control of hazards. It steps through the various safety measures to achieve an acceptable level of workplace safety. The HOC Evaluation Tool offers a numerical system that provides a way of comparing the most effective control options for various features of work.

Using this tool, should assist the stakeholders in construction projects to gain a better understanding of hazards and the related control measures. In this way an effective strategy can be developed that will improve the safety of workers, and other stakeholders, in construction projects.

Over time, this streamlined process of OSH communication on construction sites will build a better understanding of OSH risks and safety initiatives across all levels of management. It will also encourage people to focus on safety interventions that have longer-lasting benefits to workers and productivity, rather than short-term quick fixes.

4.2 An image-based tool for encouraging OSH risk communication

Introduction

Construction project stakeholders perceive OSH risks from different perspectives. The differences can be due to a number of factors, including:

- differences in professional education and training,
- specific practices and norms,
- distinct project roles and responsibilities, and
- different project interests and objectives.

The different OSH risk perceptions of project stakeholders can have significant implications for OSH risk management. This diversity of opinion needs to be encouraged in the initial stages of using the image-based tool. Through discussion this pool can be focused to the particular feature of work in order to achieve equitable and satisfactory OSH risk control outcomes.

The image-based tool

Images are an effective and straightforward method of providing information quickly and can be particularly useful in OSH discussions in the construction industry. The construction sector has a variety of stakeholders with different literacy, numeracy and comprehension skills and approaches. Some respond well to numerical depictions of hazards, risks and controls; others prefer pictorial representations such as photos, sketches and diagrams.

This research project identified an opportunity to use an image-based tool to assist stakeholders to identify hazards and potential control measures in the construction sector. This communication and consultative process would help stakeholders to understand OSH risks from other project participants' perspectives and help to integrate OSH considerations in the planning and design stages of a project.

Steps for planning and conducting a workshop using the image-based tool could include:

- identifying the relevant project stakeholder groups for the workshop,
- configuring the image-based tool and related instruction,
- engaging the stakeholders into a consultative process over their risk judgments and evaluation criteria,
- documenting the discussion results from the workshop, and
- discussing the implications of the different ideas about effective and practical controls for hazards and risks.

A workshop to explore stakeholders' perceptions of OSH would have the highest impact if it is conducted early in the project, particularly during the:

- conceptual design review stage, where fundamental changes can be made, and
- detailed design review stage, where risks could be reduced/eliminated through design changes.

This type of workshop could be beneficial during other stages in the life of construction projects when there is a design change. Relevant stakeholder groups could discuss their ideas about OSH and appropriate control strategies.

Application of the image-based tool – an example

The tool used in the OSH benchmarking research comprised images depicting a wide range of construction methods, situations and hazards. For example, eight photographs showing commonly used construction methods for façade systems were collated. Each photograph showed the façade panel as well as its installation method (see Figures 4.6 and 4.7).

Figure 4.6: Example 1 of photograph used in the research

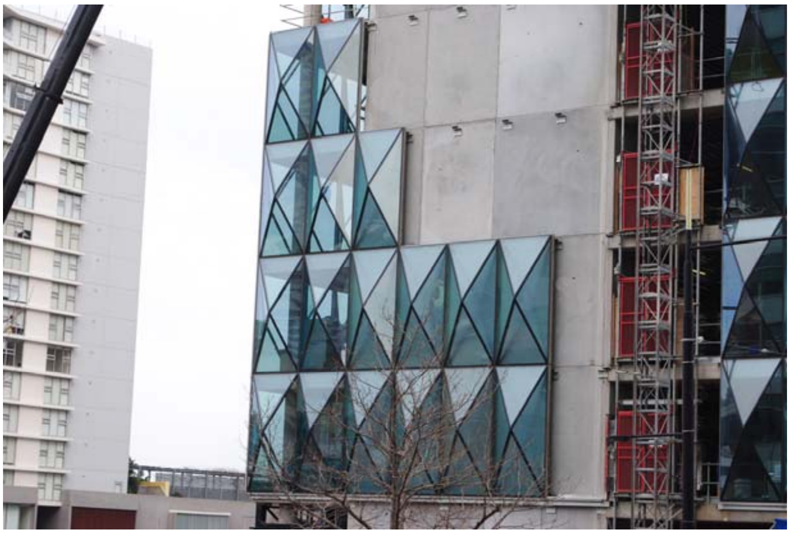

Figure 4.7: Example 2 of photograph used in the research

When used, as a practical workshop tool, the content of the images can, and should, be tailored to suit specific construction contexts and purposes. For example, images can be selected to represent:

- alternative conceptual designs for buildings,
- alternative construction processes for a building system,
- different items of plant or machinery,
- different construction methodologies for building elements (e.g. roof, façade, structure), and
- different construction methods for infrastructure.

Images are effective conversation starters on OSH matters but the image based tool is part of a hazard and control identification process and so a simple rating grid is recommended. Workshop participants would be asked to grade the images in line with how safe they believe the depicted design, process or method. The grid's columns are listed from 'safest' to 'least safe' in Table 4.8.

Table 4.8: Example of grading grid

Safest	Safer	Safe	Unsafe	Least safe

Other methods of rating the images could also be used in specific contexts. For example, stakeholder groups could be requested to make judgments about:

- the likelihood of accidental injury,
- the severity of the consequence should an accident occur, and/or
- the duration of exposure to OSH risks.

Identify relevant stakeholders

Relevant stakeholders, who could influence OSH or whose safety or health could be affected by project decision-makings, should be invited to the workshop and could include:

- clients,
- architects,
- design engineers,
- occupational safety and health professionals,
- construction managers,
- facility managers,
- construction engineers ,
- sub-contractors/tradespeople, and
- suppliers.

In the façade example, four groups of stakeholders were identified - architects, design engineers, OSH professionals, and constructors. These four groups have the most influence on, or are most influenced by OSH risks implicit in the project decision-makings in the early design stage.

Instruct the stakeholders to make OSH risk judgments

OSH risk judgments can be made on an individual or group basis, depending on the number of participants attending a workshop. In the example, participants were presented with printed images, and were requested to place the images into a printed grid on an individual basis. The participants were asked to familiarize themselves with the images first and then place the images into the grid. Table 4.9 shows an example of the sorting pattern showing the judgment of OSH risks associated with constructing the depicted façade systems.

Table 4.9: Example of image grading pattern

Safest	Safer	Safe	Unsafe	Least safe
				
				
				

Scores were assigned to the grading categories, ranging from ‘Safest’ to ‘Least safe’. For each façade image, a group average score was generated from the individual scores given by participants in the group (15 participants in each group in the example). Figure 4.8 shows the plotting of the average scores in terms of the level of safety chosen by each stakeholder group for the façade systems. The plotting indicates that the four groups graded some images (e.g. F03, F06) similarly but other images (e.g. F10, F09) very differently as indicated by the length of the vertical lines.[13]

13 For more a more detailed description of these results see Zhang, P., Lingard, H., Blismas, N., Wakefield, R. and Kleiner, B. (2015). Work-Health and Safety-Risk Perceptions of Construction-Industry Stakeholders Using Photograph-Based Q Methodology, ASCE *Journal of Construction Engineering and Management*, 141 (5), DOI: 10.1061/(ASCE)CO.1943-7862.0000954.

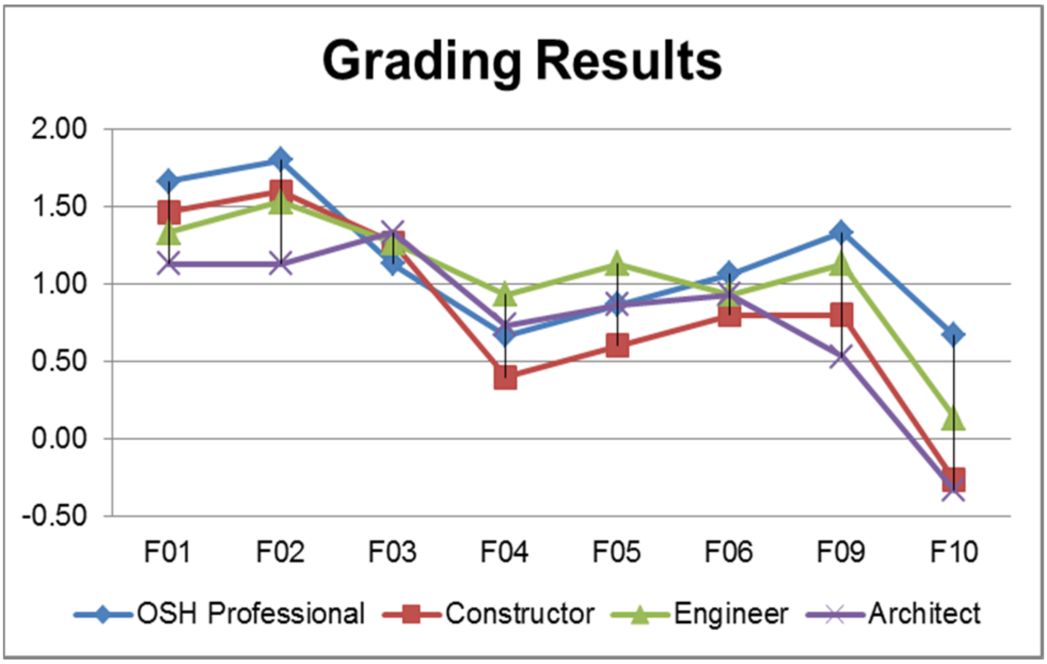

Figure 4.8: Stakeholder groups' grading results for the depicted façade systems

Consult with stakeholders

The workshop facilitator needs to follow up with open questions to explore what OSH risks participants see in the images and what evaluation criteria they have used to make risk judgments. Sample open questions could include:

- explain what OSH risks you see in these images?
- why have you picked one image as being safer or less safe than another?
- why are particular images rated safest?
- why are particular images rated least safe?

The questions can change in different contexts to facilitate the discussion of OSH risk judgments and evaluation criteria. The workshop facilitator also needs to use appropriate probing questions to elicit the underlying reasons.

Each stakeholder group should present their grid without the other group members present. This will minimize the group's selections influencing each other. Such a process would also encourage discussion between the workshop participants themselves after the "reveal" of all four groups rather than having the workshop facilitator direct the conversations.

Participants will in the process learn about their project colleagues and develop important co-operative working relationships, as well as contributing risk control measures to the session.

Document the discussion results

Risk perception is subjective and shaped by a wide range of psychological, social and cultural factors. These perceptions will differ between members of different stakeholder groups. The discussion outcomes should be documented in a way to help participants to understand:

- the evaluation criteria used by each stakeholder group to judge OSH risks, and
- whether the stakeholder groups use any similar criteria to judge OSH risk.

Table 4.10 summarizes the significant evaluation criteria used by the four stakeholder groups to judge the level of safety associated with constructing the façade systems. These criteria were mentioned by at least one quarter of participants (i.e. 25%) of one or more of the stakeholder groups.

Table 4.10: OSH risk evaluation criteria used by stakeholder groups

Number	OSH risk evaluation criteria
C1	Complexity of construction methodology (few or many systems/trades)
C2	Complexity of construction methodology (few or multiple interfaces to be coordinated)
C3	Level of safety control in place (high level versus low level)
C4	Location of installation (inside building versus outside building)
C5	Component scale (large/heavy versus small/light)
C6	Component handling method (manual handling versus machinery handling)
C7	Work level (at ground/low level versus work at height)
C8	Construction method in terms of process (off-site manufacture reduces on-site processes versus in-situ construction involves many processes)
C9	Construction method in terms of control (off site production allows more control than on site construction)
C10	Density of installation process (repetitive processes with small pieces/some processes with medium size pieces /fewer processes with large pieces)
C11	Distance (separation) between plant/load and workers/working platform
C12	Level of familiarity with a particular system (familiar versus unfamiliar)
C13	Work platform (scaffolding versus mechanical elevated work platform)

Figure 4.9 illustrates the frequency of the OSH risk evaluation criteria used by participants of each stakeholder group. Several criteria were mentioned by all of the stakeholder groups, but some criteria were only mentioned by one or two stakeholder groups.

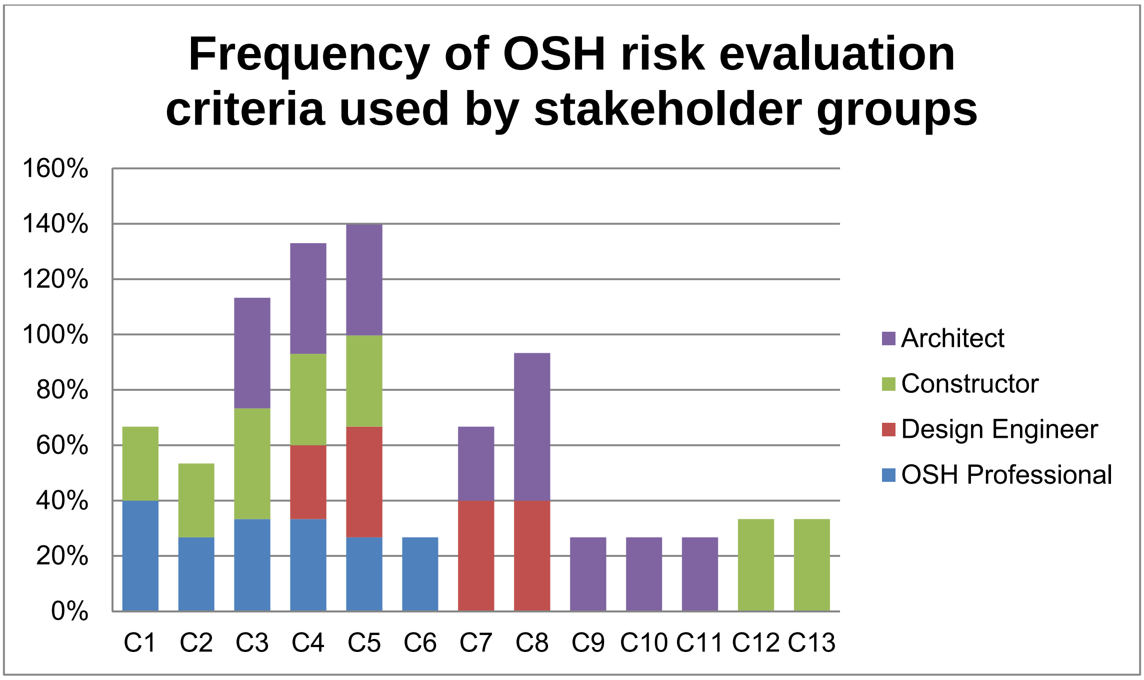

Figure 4.9: Frequency of OSH risk evaluation criteria used by stakeholder groups

Table 4.11 shows the details of the frequency of the OSH evaluation criteria with quotes from the consultative discussion process. Although some criteria (e.g. location of installation) are used by more than one stakeholder group to judge OSH risks, their relevant importance varies between groups, which is indicated by the ranking of frequencies.

Table 4.11: The explanation and frequency of OSH evaluation criteria used by stakeholder groups

Professional group	Most frequently used criteria	Example quotations	Frequency	Rank
OSH group	Complexity of construction methodology (few or many systems/trades)	"*With use of two construction methods/systems (e.g. concrete and facade), the likelihood is far more higher than using one system… integrated system with different crew/contractors involved, create more interfaces*"	40%	1
	location of installation (inside building versus outside building)	"*because the person who's operating or doing the task, like in this photo, is on the other side so there's a bit of protection, i.e. people working from inside*"	33.3%	2
	Level of safety control in place (high level versus low level)	"*What they've got there seems pretty good. Mid rails, top rails, kickers. Bracing in place, a lot of bracing in place*"	33.3%	2
	Complexity of construction methodology (few or multiple interfaces to be coordinated)	"*(This) require multiple control measures, cranes, working on height, working inside for coordination*"	26.7%	4
	Component handling method (manual handling versus machinery handling)	"*Manual lifting of blocks create moderate likelihood of injury…mechanism to system of work (creates higher likelihood)*"	26.7%	4
	Component scale (large/heavy versus small/light)	"*The only reason I say that is because I can see what plant they're using. I look at the cranes, I look at the EWPs, I look at the heights, I'm looking at the size of the panels… the size panel is much larger than that one*"	26.7%	4
Design Engineer	Construction method in terms of process (off-site manufacture reduces on-site processes versus in-situ construction involves many processes)	"*With the concrete construction, the moderate, I was a bit torn between this one because I actually think that precast is quite safe because you have less people on-site because there's more people off-site to do that and the less people you have on-site, the less chance of risk….In-situ walling, again I put in moderate because you have more people on-site and you've got more things going on. You've got people fixing bars, you've got people creating, you've got pumps coming in, there's a lot going on*"	40%	1

Professional group	Most frequently used criteria	Example quotations	Frequency	Rank
	Work level (at ground/low level versus work at height	"*I guess with all the pre-fabricated facade systems, concrete block work wall, window panels and mixed glass and concrete panels, again … moderately likely. Workers more than likely be reasonably well trained in how to use these systems, but then again I mean it's a risk of working at height. I guess once you start working at height, and especially just trying to manoeuvre these panels into place, at height, is a bit trickier. I guess it's the height issue*"	40%	1
	Component scale (large/heavy versus small/light)	"*Say a pre-cast concrete panel system for a car park, I'd probably say that was probably more likely of injury to occur, just due to the size of the panels and just due to…much larger panel. Much more difficult to control in terms of lifting*"	40%	1
	Location of installation (inside building versus outside building)	"*So this I was going to put the least risk on these facade systems because with a system like this the guys are working from inside the building so there's nobody hanging outside the building and you can put protection up so everyone's working inside the building*"	26.7%	4
Constructor	Level of safety control in place (high level versus low level)	"*Looking at them, fencing, they've all got their hand railings. They've got kickboards. So it's a moderate risk. .. Again, I'm just looking at the precast panel sections. We've got all the blokes down at the site and then I notice over the whole side of the building there's no handrail*"	40%	1
	Location of installation (inside building versus outside building)	"*It can be manoeuvred from inside, no way of floor fall, the only issue is dropping tools…work outside is always more unsafe than working inside*"	33.3%	2
	Component scale (large/heavy versus small/light)	"*Mechanical lifting may fail because of big size and big weight, there is more composition to manoeuvre, bigger areas to move*"	33.3%	2
	Level of familiarity with a particular system (familiar versus unfamiliar)	"*Precast technology, cranage, temporary work, identical. Put into unlikely because they have been around in Australia for a long time, familiar due to knowledge and experience*"	33.3%	2

Professional group	Most frequently used criteria	Example quotations	Frequency	Rank
	Work platform (scaffolding versus mechanical elevated work platform)	"*Safe because fully scaffolded system, the block works are tied to the frame, solid work platform…This system can't be secured from inside, every piece has to be placed by a crane, and [a] worker manoeuvred on a box-hang by another crane to ensure it is located*"	33.3%	2
	Complexity of construction methodology (few or many systems/trades)	"*When [you] put glass panels on concrete walls, it is harder to fix; a lot of things happening, and the degree of difficulty is higher by putting glass façade on concrete wall*"	26.7%	6
	Complexity of construction methodology (few or multiple interfaces to be coordinated)	"*Risk is higher when you use different machinery in a task, e.g. , three different people deal with tasks, one inside, one outside, and one operates crane*"	26.7%	6
Architect	Construction method in terms of process (off-site manufacture reduces on-site processes versus in-situ construction involves many processes)	"*I sort of saw the glaze systems as, because there's more pre-fabrication I suppose there's less to be done on site in a way, and it can be managed a bit better*"	53.3%	1
	Location of installation (inside building versus outside building)	"*worker lifts the façade from inside, uses suction devices, there is isolated place underneath*"	40%	2
	Component scale (large/heavy versus small light)	"*And a concrete block I saw that with less risk because it's a thing that's usually, relatively low height, less likelihood of injury because the thing's being lift are not so heavy*"	40%	2
	Level of safety control in place (high level versus low level)	"*This one's the same. They're using, again this is well done because they've got all the barriers in place. They're using, people here who are tethered, they've got all the gear*"	40%	2

Professional group	Most frequently used criteria	Example quotations	Frequency	Rank
	Density of installation process (repetitive processes with small pieces/some processes with medium size pieces /fewer processes with large pieces)	"*Has scaffolding, kind of safety; but work with a lot of units of blocks, by comparing work with a number of panels in unlikely column ,here need to work thousands units, more possibility to make mistakes, high likelihood of drop blocks, drop tools*"	26.7%	4
	Construction method in terms of control (off site production allows more control than on site construction)	"*Here are all prefabricated items which would have been the subject of shop drawings, and so you would expect that the installation tolerances would be fairly accurate*"	26.7%	4
	Work level (work at ground/low level versus work at height)	"*for most part, people work on the ground, there is no likelihood of fall*"	26.7%	4
	Distance (separation) between plant/load and workers/working platform	"*there is mobile crane boom lifting the panel with suction cap, on the way of lifting there is a worker working on a cherry picker, the boom could knock the worker's head*"	26.7%	4

Discuss the implication of the different OSH risk perceptions on integrating OSH considerations in design and planning stage

The workshop facilitator could then use a brainstorming session to engage the participants to openly discuss the implication of the different OSH risk perceptions on integrating OSH considerations in the design stage. The workshop facilitator could lead the participants to discuss issues such as:

- what risks could be reduced/eliminated if different perspectives were considered in design activities
- how risks could be most effectively reduced/eliminated by design alternatives,
- what control measures would be the most effective, and
- what could be done in practice to design out hazardous features of work.

This type of discussion could be very useful in design review meetings as it would help in the development of a comprehensive risk assessment and effective risk control strategies.

So what does this all mean?

The image based tool is intended to offer an alternative, or complementary way, of grading OSH risks and identifying controls compared to the numerical process in the hierarchy of controls Evaluation Tool. Some in the construction industry respond better to using images rather than numbers or words. Some also respond positively to the physical movement of images to establish thought paths and linkages between work processes, particularly those between hazards and control measures.

Although this section has focused on photographs, the tool could work equally well with sketches, illustrations, animations, models or any other visual medium. Alternatives to photographs are encouraged as long as they meet the needs of workshop participants.

The tools in this report have the ultimate aim of reducing the risk of harm to workers in the construction sector. This aim can be achieved through talking about safety, risks, and controls with a range of stakeholders. These tools show possible ways of structuring that discussion so that stakeholders understand the perspective of others and from here can develop a coordinated strategy for worker safety that also meets the needs of the broader construction sector.

Part 5: Further Reading

Journal papers

Lingard, H., Cooke, T., Blismas, N., and Wakefield, R., (2013). Prevention through design: Trade-offs in reducing occupational health and safety risk for the construction and operation of a facility, *Built Environment Project and Asset Management*, 3 (1), pp7-23.

Lingard, H., Pirzadeh, P., Blismas, N., Wakefield, R., & Kleiner, B., (2014). Exploring the link between early constructor involvement in project decision-making and the efficacy of health and safety risk control, *Construction Management and Economics*, 32 (9), pp918-931, DOI: 10.1080/01446193.2014.911931

Lingard, H., Saunders, L., Pirzadeh, P., Blismas, N., Kleiner, B., & Wakefield, R. (2015). The relationship between pre-construction decision-making and the effectiveness of risk control: Testing the time-safety influence curve, *Engineering, Construction and Architectural Management*, 22 (1), pp108-124.

Lingard, H., Zhang, R.P., Blismas, N., Wakefield, R. & Kleiner, B. (2015). Are we on the same page? Exploring construction professionals' mental models of occupational health and safety, *Construction Management and Economics*, 33 (1), pp73-84, DOI: 10.1080/01446193.2015.1016541

Zhang, P., Lingard, H., Blismas, N., Wakefield, R., & Kleiner, B. (2015). Work health and safety risk perceptions of construction industry stakeholders using photograph-based Q-methodology, *Journal of Construction Engineering and Management*, 141 (5). DOI: 10.1061/(ASCE)CO.1943-7862.0000954.

Conferences

Wakefield, R., Lingard, H., Blismas, N., Pirzadeh, P., Kleiner, B., Mills, T., McCoy, A. & Saunders, L. (2014). Construction Hazard Prevention: The Need to Integrate Process Knowledge into Product Design. In proceedings of CIB W099 International Conference Achieving Sustainable Construction Health and Safety, R. Aulin and A. Ek (ed.), Lund University, Lund, Sweden, pp. 425-435.

Zhang, P., Lingard, H., Blismas, N., Wakefield, R., & Kleiner, B. (2013). Application of Q-methodology in studying construction stakeholder's perceptions of OSH risks – An introduction to the preliminary stage. In S., Kajewski, K., Manley, & K., Hampson (Eds.), Proceedings of the 19th Triennial CIB World Building Congress, Brisbane, Queensland, 5-9 May 2013, pp. 1-12.

Zhang, P., Lingard, H., Blismas, N., Wakefield, R., & Kleiner, B. (2014). Analysis of difference/similarity between construction project stakeholders' work health and safety (WHS) risk perceptions. Paper presented in CIB W099 International Conference on Achieving Sustainable Construction Health and Safety, 2-3 June 2014, Lund, Sweden.