ON-LINE OH&S RISK ASSESSMENT FOR CONSTRUCTION DESIGNERS: THE 'TOOLSHED' PROTOTYPE

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Many occupational health and safety (OH&S) problems encountered during the construction, operation and maintenance of a facility could be avoided by ensuring that sound risk management practices are adopted during the design stage. OH&S risks identified after the completion of the detailed design stage of a construction project are often more difficult to eliminate or reduce and can also result in unnecessary costs and delays to the project. While some effort has been made to assist designers to integrate OH&S into their decision-making, existing guidelines rely on the ability of the designer to identify, assess and appropriately control 'foreseeable' risks. The effectiveness of the design OH&S concept is heavily reliant on a designer's knowledge and competence in risk management. Not only do designers need to be aware of the features of their design that constitute OH&S hazards, but they need to know how to implement a risk management process to assess the magnitude of the risk presented by these hazards and make sensible decisions about how OH&S risks should be treated. A prototype web-based, knowledge-based system (KBS) has been constructed, that provides a step-by-step risk assessment consultation for construction designers. This consultation can be undertaken by designers with minimal understanding of risk management concepts. The program uses a simple but effective way of modelling expert reasoning in the assessment of OH&S risk and replicates the decision-making of experts in design OH&S, with input from experienced 'users' of design outputs, i.e. constructors, facilities managers and maintenance personnel.

Key words: knowledge-based systems, maintenance, OH&S, risk management, safe design.

INTRODUCTION

This paper describes a research and development project in which a prototype on-line decision support tool was developed to guide construction designers through the risk management process. The rationale for the tool, known as ToolSHeD (Tool for Safety and Health in Design) is presented and the method of modelling OH&S risk reasoning is explained. Funded jointly by the Department of Communications, Information Technology and the Arts in Australia, the aim of the one year project was to determine the viability of further development of the conceptual design programme.

CONSTRUCTION OH&S

Construction is one of Australia's highest risk industries (NOHSC, 2005). In 2002 – 2003 people working in the construction industry were more than twice as likely to be killed at work as the average worker in all Australian industries. Further, 2005 figures indicate that construction is Australia's third most dangerous industry, surpassed only by transport and storage, and agriculture (Fraser, 2007). The incidence of

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compensated claims for the industry is almost three times the national average for all industries (NOHSC, 2005).

DESIGN IMPACTS ON OH&S

A number of studies have demonstrated that decisions made during the design stages of a construction project significantly impact on OH&S during construction, occupation, maintenance and demolition (Weinstein, *et al.* 2005; Williams 1998). Root cause analyses of construction accidents reveal that many construction accidents can be attributed (at least in part) to OH&S risks created well before work commences on site, most notably in the planning and design stages (Bomel, 2001, Suraji *et al.* 2001; HSE 2003). According to an often-quoted report by the Commission of the European Communities (1993) around 60% of all fatal construction accidents can be traced back to decisions made during project design and planning.

In the Australian construction industry, the design OH&S concept is relatively new, but is rapidly gaining momentum. The National OHS Strategy 2003 – 2012 (NOHSC 2002) identifies "eliminating hazards at the design stage" as one of five national priority areas. Further, the strategy states that the "responsibility to eliminate (OH&S) risk rests at the source" (NOHSC 2002, Pg 9). Within the construction industry, the source of OH&S risk is sometimes the design team, presenting construction design professionals with considerable opportunity to eliminate or reduce OH&S risks throughout the project life cycle. Choices about the design, methods of construction and materials used can all significantly impact upon OH&S of those who build, occupy, maintain, clean, renovate, refurbish or eventually demolish the building/structure at the end of its useful life (ECI 1996; Hinze and Gambatese 1994).

It is also believed that the identification and treatment of OH&S issues at the design stage is less difficult and costly than attempting to treat significant OH&S risks identified after the completion of the detailed design stage (see Figure 1). Risk treatment at the design stage is also consistent with the selection of preferred technological control measures (i.e. the physical elimination or risk reduction through engineering design) for OH&S risk.

DESIGN OH&S LEGISLATION IN AUSTRALIA

In Australia OH&S is regulated at a State/Territory level. In some jurisdictions (Western Australia, South Australia, Victoria and Queensland) specific statutory obligations for construction designers have been established. Thus, to varying degrees, construction designers in these States are required to eliminate or reduce OH&S risk to persons who construct, occupy or maintain the facilities they design.[1] Despite these new obligations, construction designers in Australia are generally not well informed about OH&S. Industry guidelines, such as *Designing Safer Buildings and Structures* (WorkSafe Victoria, 2005) have been developed in an effort to assist designers to manage OH&S risks inherent in their designs, however these guidelines assume a designer's ability to identify and assess 'foreseeable' OH&S risks – an assumption that might not be reasonable.

[1] Note that design OH&S requirements differ between jurisdictions. Thus, in Western Australia the design OH&S requirement expressly mentions designing for the OH&S of persons who will construct the building/structure, while the Victorian legislation is interpreted by WorkSafe Victoria as relating only to the OH&S of end users. The position in South Australia is ambiguous and in no jurisdiction has the scope of designers' OH&S responsibilities been adequately tested and established in case law.

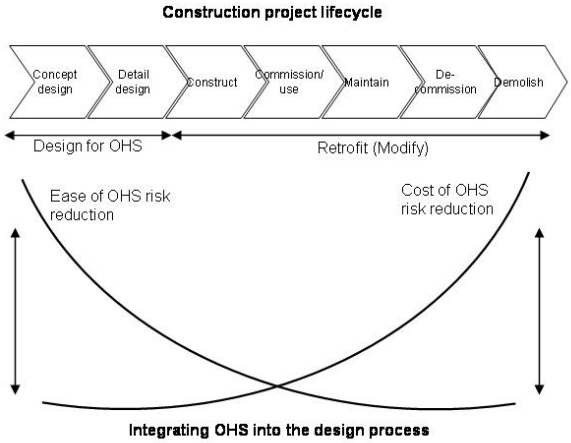

Figure 4: Integrating OHS into construction design (adapted from NOHSC2003)

DESIGNERS' OH&S COMPETENCIES

Research shows that many construction design professionals are not sufficiently conversant with the risk management process to fulfil these legal responsibilities effectively. In the UK, specific OH&S obligations for construction design professionals have been in place for more than ten years, yet relatively recent research indicates that there is still a great deal of uncertainty among design professionals about how to comply (Summerhayes 2002). Recent US research exploring construction designers' OH&S attitudes revealed that around only one third of the designers interviewed showed an interest in safe design concepts. However when asked to prioritize project criteria, end user safety was considered the second most important criteria, following only quality of work (Gambatese, 2005). It seems that designers differentiate between operational safety (i.e. that of the end user of the designed facility) and occupational safety (i.e. that of persons who work on in or around the facility throughout its life cycle). Further Gambatese (1997) identified designers' lack of OH&S training as a factor impeding the integration of OH&S into construction design. Tool (2002, pg 205) states that a person 'who has not been trained – either through classroom or on the job instruction – may not be able to recognize and avoid all potential hazards associated with the task he or she is performing' suggesting that a lack of appropriate training for design professionals is likely to moderate their ability to manage OH&S risk in their designs.

RISK MANAGEMENT AND OH&S LEGISLATION

Since the mid -1970s in the United Kingdom and the early 1980s in Australia, OH&S legislation has moved away from a detailed prescriptive model to a more flexible performance -based approach. In this approach broad general duties are established for groups of persons, including employers, employees, the self-employed, designers, manufacturers and suppliers of plant – and now designers of buildings and other structures (Gunningham, 1996). Underpinning this legislation is the notion that OH&S risk must be reduced 'so far as is reasonably practicable'. The practical method of compliance with this type of legislation is to be determined by duty holders who must demonstrate that they have done all that is 'reasonably practicable' to eliminate or

reduce OH&S risk. Ultimately the duty holder must determine 'how safe is safe enough'.

The legislation offers some explanation of the factors that determine what is reasonably practicable in a given situation. For example, in the State of Victoria, Section 20 (2) of the OH&S Act (2004) states that, in determining what is reasonably practicable, regard must be had to the following matters:

- the likelihood of the hazard or risk concerned eventuating;
- the degree of harm that would result if the hazard or risk eventuated;
- what the person concerned knows, or ought reasonably to know, about the hazard or risk and any ways of eliminating or reducing the hazard or risk;
- the availability and suitability of ways to eliminate or reduce the hazard or risk; and
- the cost of eliminating or reducing the hazard or risk.

The judgment as to what constitutes 'reasonably practicable' must refer to an assessment of the risk inherent in a particular activity, as well as the opportunities and costs of risk elimination or reduction. There is an expectation that duty holders are informed about OH&S risk and methods by which it can be controlled, and are able to competently identify hazards and assess the degree of risk they present and take steps to eliminate or reduce OH&S risks that are proportionate with the level of risk posed. This expectation presents a significant problem for duty holders who have not been trained in OH&S, who do not understand risk concepts and are not practised in the application of risk management to OH&S.

THE RISK MANAGEMENT PROCESS

The risk management process, as set out in AS/NZS 4360 and depicted in Figure 2, is an iterative process, involving a continuous cycle of risk identification, assessment and treatment. The assessment of risk informs risk treatment (or control) decisions, the implementation of which is monitored and reviewed to ensure that risks are properly managed and remain within tolerable limits. Where risks are deemed to be unacceptably high, decisions must be made about how to treat these risks, either by abandoning the risky activity altogether, eliminating or reducing the risk.

MANAGEMENT OF OH&S RISK

One problem for the management of OH&S risk is the lack of reliable, objective data upon which to base quantitative risk analysis. Consequently, OH&S risk assessment are often imprecise and based on the subjective judgement and opinions of the assessor (Pidgeon *et al.* 1993). Studies have shown that perceptions of risk are subject to considerable bias, leading people to overestimate certain risks while underestimating others (Slovic, *et al.*, 1980).

Assessments of OH&S risk are inevitably based upon the knowledge, experience and values of the people who are involved. Assessors explicitly (or implicitly) make judgements about the magnitude of OH&S risks, cost effectiveness of risk treatments and the degree of risk which should be tolerated. Given the degree to which individual knowledge and judgement influence assessments of OH&S risk, it is of great importance that assessors are competent in risk management and knowledgeable about OH&S. This problem is exacerbated by the use of the risk management lexicon, (e.g.

'hazard,' 'risk,' 'assessment,' 'analysis,' 'estimation' and 'evaluation') in everyday speech, further confusing duty-holders (Waring *et al.*, 1998).

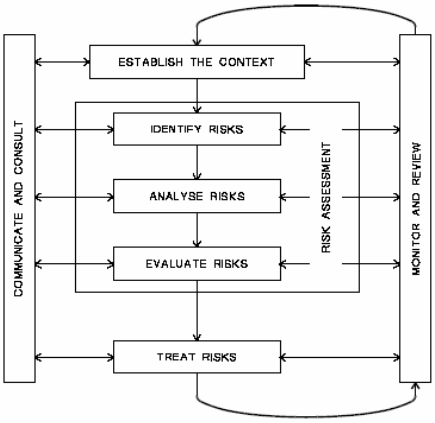

Figure 5: The risk management process (adapted from AS/NZS 4360)

The uncertainty and complexity implicit in the assessment of OH&S risk has reportedly posed a problem for construction designers in the UK (Rigby 2003). Additionally, Durham (2002) suggests that current risk management processes carried out in the building and construction industry result in the documentation of minimal compliance requirements to avoid prosecution, rather than adopting a *bonafide* risk management approach as intended by the legislation (Durham, 2002).

OH&S RISK AND SAFE DESIGN

The UK experience has demonstrated that the inclusion of design safety requirements in OH&S legislation does not automatically deliver reductions in OH&S risk in the building and construction industry. Given the lessons from the UK, the achievement of 'safer' design in the Australian construction industry is likely to depend upon the readiness of construction design professionals to accept responsibility for OH&S and proactively work to integrate OH&S risk management into the construction design process. The acceptance of construction design professionals' responsibility for OH&S seems evident in the fact that professional bodies, such as the Royal Australian Institute of Architects and Engineers Australia, are contributing to the development of a voluntary code of practice establishing roles and responsibilities of clients, designers and constructors in improving Australia's appalling OH&S record in construction. Given this apparent acceptance of design OH&S responsibility, the ability to integrate OH&S risk management into design decision-making remains a challenge. Presently, very few tools or resources are available in Australia to assist with this.

THE 'TOOLSHED' PROTOTYPE

A consortium comprising of the School of Property, Construction and Project Management (RMIT University) and two private companies, have developed a prototype web tool to help architects and engineers make design-decisions that take account of OH&S. The one-year project was funded jointly by the Information Technology Online (ITOL) Program of the Department of Communications, Information Technology and the Arts in Australia. The prototype, known as ToolSHeD (Tool for Safety and Health in Design), is briefly described below.

ToolSHeD aims to assist construction designers to integrate OH&S risk management into their design decision-making by stepping them through an on-line risk assessment

consultation. OH&S is an area in which learning from one's mistakes is undesirable, making the provision of expert reasoning in a knowledge-based decision support tool particularly useful. ToolSHeD re-produces the reasoning used by a panel of experts to assess the OH&S risk associated with relevant features of a building design.

At present, the scope of ToolSHeD is restricted to the risk of falling from the roof of a building during maintenance. The reason for this is that ToolSHeD was developed with a modest grant and the purpose of the initial research and development task was to test an innovative method of modelling OH&S risk information. Once the usefulness of this method was proven, ToolSHeD could be developed to provide a more comprehensive design OH&S risk assessment capability. Initially, design decisions affecting the completed facility, rather than those affecting constructability, were selected as these are most prominent within Australian, and particularly Victorian legislation.

Further, falls from roofs during maintenance were selected for the prototype because fall hazards are the Australian building industry's most frequent cause of accidental death and the second largest cause of non fatal injuries. Recent research in Hong Kong revealed nearly one third of accidents in the construction industry occurred during maintenance and repair works (Yam, 2006) and an analysis of five years of construction fatalities in the UK showed that between 34 and 50% of construction fatalities occurred during maintenance, of these the largest proportion involved falling through or from a roof (HSE, 1988).

MODELLING RISK INFORMATION

ToolSHeD utilizes an innovative method for modelling OH&S risk information. The reasoning used by specialists in assessing the risk presented by a building design is captured and represented in a series of 'argument trees.' The use of 'argument trees' to represent expert knowledge was pioneered in a model of reasoning developed by Yearwood and Stranieri (2005) and has been successfully used to structure and represent knowledge in various fields of legal reasoning, including family law, refugee law and eligibility for LegalAid.

Argument trees consist of a number of 'child' and 'parent' nodes ultimately feeding into a single 'root' node. Throughout the argument tree, a linguistic variable value on a 'parent' node is inferred from values on 'child' nodes, with the use of predetermined inference procedures. An inference procedure is essentially a mapping of child variable values to parent variable values, ultimately representing a template for reasoning in complex situations. Thus argument trees capture a shared understanding of relevant factors in the determination of a value.

The argument trees within ToolSHeD, represent the hierarchy of factors relevant to the assessment of a design-related OH&S risk. In the ToolSHeD prototype, the risk rating is the root node at the top of the trees. The linguistic variables "extreme", "high", "moderate" and "low" are used to denote the magnitude of the risk at this root node.

Consistent with risk management principles, the risk rating is inferred with knowledge of three factors: the likelihood that an injury or illness will occur; the likely severity of the consequence of that injury or illness should it occur, and the degree of exposure to the risk. Thus, in the case of the prototype, the risk rating is inferred from values representing the likelihood of a fall from a roof during maintenance, the likely severity of consequence should a fall occur and the frequency of exposure to the risk (i.e. the

amount of time people will be required to spend performing maintenance on the roof of the building). In standard qualitative risk assessment only the likelihood and consequence are considered. The top level argument tree is shown in Figure 3. In total, the knowledge behind the ToolSHeD prototype is represented in 10 different trees, all of which feed into this top level tree. For all the trees developed, the 'parent node' is the OH&S risk rating. The parent node is the final node into which all other nodes ultimately feed and always appears to the right of the argument tree.

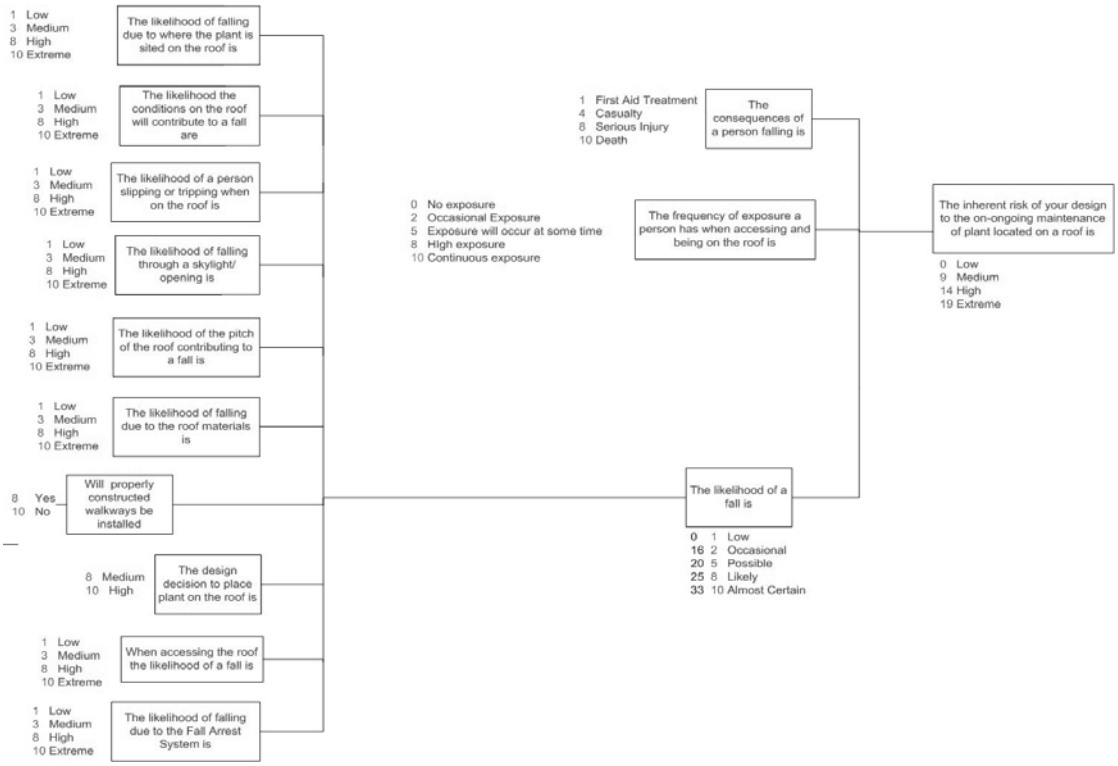

Figure 3: Top Level Tree from ToolSHeD

An example of how the inference procedure operates can be seen in Figure 4. The designer is prompted to respond to a series of statements, gathering information about relevant aspects of the building design. The designer is only prompted to respond to statements relating to factors that are shaded in Figure 4. For example, designers are asked to indicate the type of roof access provided for in the design. The probability of falling is inferred from the location and method of roof access. This inference (along with other similar inferences) will ultimately contribute to an assessment of the likelihood of falling from the roof.

To capture the expert reasoning contained within the ToolSHeD prototype, a Delphi process was used. An expert panel including designers, facilities managers, engineers, building surveyors and OH&S specialists attended a workshop at which the argument trees were presented. The trees were refined by panel members in an iterative process until consensus was reached. The list of potential hazards generated by the Expert Panel formed the basis for the risk assessment.

Given the number of relatively high number of design issues identified as being relevant to the risk of falling from a building roof during maintenance, the 'argument trees' were divided into sections, each of which constitutes a component of the complete tree (Table 1). One advantage of grouping relevant design factors in a series of smaller trees is that this makes knowledge modelling more manageable. Another

advantage is that it permits the exclusion of certain design features that contribute to an OH&S risk. For example, not all building design include skylights, a known OH&S hazard. By eliminating prompts relating to skylights at the beginning of a risk assessment consultation only relevant information is requested from designers and utilized in the inference process.

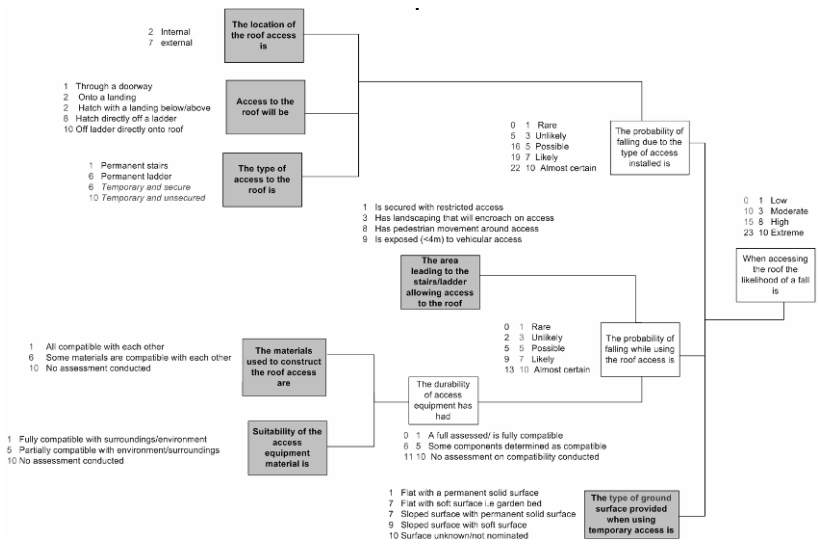

Figure 4: Sample Argument Tree showing inferences

Table 1: Design aspect groupings from which the likelihood of a fall is inferred.

Likelihood Argument Tree Grouping	No. of relevant factors within tree
Siting of Plant	8
Location on roof Plant	17
External Conditions	18
Roof Access	10
Slips and Trips	13
Fall Arrest Systems	10
Skylights	15
Pitch of Roof	6
Walkways	2
Roof Covering	4

TOOLSHED OUTPUTS

Once a ToolSHeD risk assessment has been completed, a report is produced. This report summarizes the OH&S risk implication of all the design information entered. An overall risk rating is provided along with ‘map’ that allows the tracking of the impact individual design features on this rating.

The primary purpose of the output is to provide the designer with an objective assessment of the level of OH&S risk (relating to falling from a roof during maintenance work), as well as enabling a designer to identify the features of a building design that contribute significantly to this risk. On the basis of this information, a designer could accept the risk implications of the design or else re-visit particular design features to reduce the risk to an acceptable level. The secondary purpose of ToolSHeD is to provide construction designers with an understanding of design safety risk assessment and better appreciate the OH&S implications of features of their designs. Users of knowledge based systems, such as ToolSHed, are reported to implicitly learn the knowledge embedded within these systems (Antony *et al.*, 2006).

PRELIMINARY VALIDATION

To verify the data captured in the argument trees, three sample risk assessments were conducted, one on a proposed design, the other two on existing buildings with plant located on the roof. The results of the risk assessments have demonstrated that the design options selected at the child nodes of the trees accurately inferred the risks and that the hazards faced with having plant located on a roof have been adequately captured.

Originally designed to address risks at the concept stage of a design, ToolSHeD has proven to be equally informative on existing buildings were Facilities Managers are faced with the decision to upgrade roof top work areas.

CONCLUSION

Currently, construction design professionals in Australia possess limited OH&S or risk management knowledge or experience, despite now having statutory OH&S obligations in a number of States and Territories. There is little guidance available on how to assess the OH&S risk implications of a building's design. Construction designers are left to sift through what they consider to be the features of their designs relevant to OH&S risks, using their subjective judgement to assess risks and make decisions about what constitutes 'reasonable practicability' in design OH&S risk reduction. ToolSHeD provides a consistent basis for the assessment of design-related OH&S risks in the building/construction industry. The prototype is presently limited in scope, however, the argument tree, risk management methodology and computer modelling and inference techniques have been demonstrated to work. It is envisaged that further development of ToolSHeD will provide a more comprehensive, reliable analytical tool that will facilitate the integration of OH&S risk management into construction design decision making.

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