LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-JRNL-461830

Review of Qualitative Approaches for the Construction Industry; Designing a Risk Management Toolbox

D. M. Zalk, T. Spee, M. Gillen, T. J. Lentz, A. Garrod, P. Evans, P. Swuste

November 9, 2010

Safety and Health at Work

REVIEW OF QUALITATIVE APPROACHES FOR THE CONSTRUCTION INDUSTRY; DESIGNING A RISK MANAGEMENT TOOLBOX

Submitted to The Annals of Occupational Hygiene

Zalk DM[1], Spee T[2], Gillen M[3], Lentz TJ[3], Garrod A[4], Evans P[4], Swuste, P[5]

1) Lawrence Livermore National Laboratory, PO Box 808 L-871, Livermore, CA 94551 USA zalk1@llnl.gov
2) Arbouw, PO Box 213, 3840 AE Harderwijk, the Netherlands spee@arbouw.nl
3) National Institute for Occupational Safety and Health mgillen@cdc.gov tbl7@cdc.gov
4) Health and Safety Executive, paul.evans@hse.gsi.gov.uk, andrew.garrod@hse.gsi.gov.uk
5) Delft University of Technology, Safety Science Group, P.O.Box 5015, NL-2600 GA Delft, the Netherlands p.h.j.j.swuste@tudelft.nl

Abstract

This paper presents the framework and protocol design for a construction industry risk management toolbox. The construction industry needs a comprehensive, systematic approach to assess and control occupational risks. These risks span several professional health and safety disciplines, emphasized by the United States (US) National Institute for Occupational Safety and Health National Occupational Research Agenda mentioning projects for not less than seven topics: falls, electrocution, struck-by hazards, noise, silica, welding fumes, musculoskeletal disorders. Yet, according to the International Social Security Association, "whereas progress has been made in safety and health, the construction industry is still a high risk sector." Small- and medium-sized enterprises (SMEs) employ about 80% of the world's construction workers. In recent years a strategy for qualitative occupational risk assessment and risk management, known as Control Banding (CB) has gained international attention as a simplified approach for reducing work-related risks. CB groups hazards into stratified risk 'bands', identifying commensurate controls to reduce the level of risk and promote worker health and safety. We review these qualitative solutions-based approaches and identify strengths and weaknesses toward the design of a simplified Control Banding systematic 'toolbox' approach for use by SMEs in construction trades. This toolbox design proposal includes international input on multidisciplinary approaches for performing a qualitative risk assessment determining a risk 'band' for a given project. The risk band is used to identify the appropriate level of training to oversee the work, leading to commensurate and appropriate control methods to perform the work safely..

Key words: control banding, construction toolbox, barrier banding, risk level based management system, universal precautions, qualitative risk management, risk assessment

Introduction

The construction industry is serviced by a collection of trades, many of which have attendant hazards, a high risk of injury or illness, and involve working in a changing environment. Despite the existence of recognized and effective solutions and guidance for reducing risks from these hazards too frequently they are poorly implemented. The consequences of construction hazards can be severe in terms of morbidity and mortality. Analysis of these incidence data calculated an average cost of US$27,000 per incident in construction, almost double the US$15,000 cost per case for all industry (Waehrer *et al*., 2007).

An estimated 7% to 10% of the global workforce works in the construction industry. But the sector accounts for 30% to 40% of occupational fatal accidents worldwide: at least 60,000 per year (Murie, 2007; ILO, 2005a). The risks are similar worldwide, and are in many cases safety-related (Holmes *et al*., 1999). Falls from heights can cause significant injuries, are often fatal, and the fundamental approach necessary to prevent this accident outcome was described over 3300 years ago [Deuteronomy 22:8]. Even so, the numbers for construction fatalities, injuries, and related costs are generally flat or continue to rise in the US, New Zealand, Taiwan, and The Netherlands (NL) (Ale *et al*., 2008; BLS, 2007; Bentley, *et al*. 2006; Chi *et al*., 2005).

In addition to injury risks, construction workers are also exposed to a variety of health hazards. Potential hazardous substance exposures include:

- solvent vapours from glues and paints
- acids and alkalis used for cleaning
- reactive compounds such as epoxy resins
- insulation materials, e.g. mineral wool
- 'natural' products e.g. quartz from a stone, concrete or brick cutting, wood dust
- fume from heating or burning, e.g. torch cutting, welding, diesel exhaust, bitumen

Many construction tasks also present physical hazards, e.g. noise, vibration, and handling loads. Occupational hearing loss in the construction sector remains significant, even in nations with strong regulations (Nelson *et al*., 2005). An estimated 30% of construction workers have musculoskeletal disorders (MSD) and back pain, even though basic solutions have been available for 100 years (ILO, 2005a; Weinstein *et al*., 2007). Industry recognition of health hazards is lower than that for injury hazards. The casual nature of employment in construction is likely to conceal disorders and diseases. For example, MSDs could cause the worker to leave construction, or respiratory disease might not develop until later in life. Complaint data from NL indicate construction workers generally do not complain about hazardous substances, with the exception of a few specific jobs. However, over 50% of all construction laborers complain about dust, apparently without being aware that virtually all construction dust contains hazardous substances like silica and wood (van Thienen and Spee, 2008). Even when implemented nationally, control solutions are rarely known or used widely, despite near-identical hazards.

<u>Construction Industry Needs</u>

The construcion industry is dominated by SMEs who lack full time safety and health staff. In the US and NL for instance, about 80% of the construction companies are SMEs with fewer than 10 employees (USCB 2004; Waeireer 2007; Geraedts and Wamelink 2008) and in Great Britain (GB) they account for 73% of the industry's fatalities (HSE 2008). As is true with general industry, the accident and occupational disease rates are often twice as high among SMEs, compared with large enterprises (Malchaire 2004). The construction industry is highly competitive and work is typically awarded to the lowest bidder. Construction worksites are by their nature temporary, and typically involve multiple contractors and subcontractors each present for only a portion of the project. These and other attributes contribute to hazards and complicate national safety and health enforcement efforts. The end result is that poor occupational safety, health and hygiene (OSHH) protection and enforcement shift disproportionate human and economic costs to the construction worker, their families and communities, (Watterson 2007). Globally, construction employers commonly utilize immigrant workers. These employees typically speak non-native languages, may have low literacy skills resulting in many languages being spoken on a worksite, and may have general communication issues between employers and employees that go beyond language and literacy (Rath, 2002). Small employers often do the same job as their employees and are without time to search for prevention, risk assessment, and control information. As construction industry management is often output-oriented, as long as quality, time, and cost criteria are met, little thought is given to ensure protective measures are used and followed. Often employees decide how the job is done. Therefore, 'solutions initiatives' are best aimed at employee and employer (Watterson, 2007).

It is unrealistic to expect most SME employers to distinguish among separate OSHH fields. Small construction employers have been shown to view OSHH risks as the responsibility of employees instead of something integrated into their company management systems (Holmes, 1995). Few understand accident prevention or detailed hazard awareness, often with controls unavailable or opting for the cheapest control measure (Lingard and Holmes, 2001; Haslem, 2005). Regulatory enforcement of control measure use is weakest with construction SMEs, and nearly non-existent in most countries for accident and MSD prevention (Haslem, 2005; Vedder and Carey, 2005; Watterson, 2007). Effective enforcement as a means of promoting control solutions use requires intense and sustained efforts that is unlikely to occur given limited resources and expertise. Consequently, more effective approaches will involve better mechanisms for reaching SMEs with holistic solutions to industry challenges, rather than a reliance on enforcement and punitive strategies.

Health and Safety Perspectives

Construction hazards have received considerable attention over the last two decades. Researchers internationally have examined hazards, consequences, and costs and developed numerous interventions and tailored controls (Thienen and Spee, 2008; LI, 2008; BLS, 2007; CDM, 2007; Waterson, 2007; Flanagan *et al*., 2006; Haslem *et al*., 2005). Construction has also grown as a specialty practice area for OSHH professionals. Although injury and fatality rates have become relatively flat over the last two decades for larger firms, injury rates remain high for SME construction firms. Numerous research needs remain and transfer of research from peer-reviewed journals to construction practice, and between countries, has been slow. There is increasing recognition that implementation of evidence-based public health interventions of all types is hampered by the near total absence of systems and infrastructure for marketing and distributing information to end users (Kreuter and Bernhardt, 2009). Many countries are getting more involved with transfer, ranging from developing “Research to Practice” programs in the US, to improved packaging of technical guidance in GB, to industry in NL. Increasingly, research programs are attempting to develop more comprehensive approaches to transfer research findings to practice.

Respirable quartz dust (silica) provides an excellent example of these gaps and challenges. Silicosis in construction has been an issue for decades and preventative methods well known to OSHH professionals (Wagner, 1995). Awareness of silica hazards among SME contractors has lagged behind awareness of injury hazards. Silica as a recognized hazard in NL began getting attention in the early 1990s (Lumens and Spee, 2001). Despite several initiatives taken to reduce silica exposure in construction, inconsistent application of control measures has led to early signs of silicosis in newer construction workers (Onos *et al*., 2003; Tjoe Nij and Heederik, 2005). Since then, the Dutch government and the sector jointly invested approximately 16 million euro for developing and implementing measures to reduce silica exposure (Staatscourant, 2001). In 2007, however, Dutch Labor Inspectorate inspections showed only 30% of the construction companies take measures against dust at high exposure levels (LI, 2008), a figure which is exactly the same as it was before this investment (Onos et al, 2003). In NL, therefore, one can conclude that the investment has not led to implementation of more control measures, so far.

Increasingly important is focusing on preventive and control methods for common work-related hazards (Kristenson, 2005). In shifting the focus to 'prevention', it is vital to transfer information comprehensibly, so workers and employers can understand the hazards and risks, how they apply, and how to use the control measures properly (Fingerhut, 2008; NIOSH, 2009). To significantly affect injury and illness rates in the construction industry, a consistent and coordinated message must present a simplified method for ensuring risk assessment, risk prioritization, and workable solutions readily available to workers. Given the similarity of construction hazards and control implementation problems across different countries, a strong case can be made for increased global collaboration and better utilization of limited resources.

Objective

Several initiatives have been presented to overcome the variety of hazards in the construction industry that are multidisciplinary and multinational. The National Institute for Occupational Safety and Health

(NIOSH) National Occupational Research Agenda identifies priority construction challenges and related goals for seven specific hazards: falls, electrocution, struck-by hazards, noise, silica, welding fumes, and MSDs (NIOSH 2008). The International Social Security Association has created a construction-based declaration stating "whereas progress has been made in safety and health, the construction industry is still a high risk sector with respect to accidents and occupational diseases, often resulting in premature death or disability retirement" (ISSA, 2009). The declaration resolves to "all nations" that "massive action must be taken" to address this situation and "the main focus should be risk prevention." NIOSH resource also notes "construction work is an important example for showing how an application moving directly to exposure controls based on the task performed is the best use of the Control Banding strategy" (NIOSH, 2009). The purpose here is exploring possibilities for a multidisciplinary approach addressing these initiatives utilizing international input. The goal of this paper is investigating the feasibility of utilizing CB strategies to develop a toolbox model that addresses risk prevention for the hazards that threat the construction worker.

Methods

This analysis is divided into two parts: (i) overview of solutions-based models to derive multidisciplinary elements necessary for the construction industry and (ii) designing a toolbox framework to develop risk 'bands' for construction projects and identify commensurate control methods to perform comparable work safely. The overview provides a presentation of available solutions-based models are discussed and analyzing them according to their strengths and limitations. Emphasis is given to research findings that can be standardized into usable information products for contractors and workers ensuring solutions generated can be transferred between countries. An original toolbox framework is then designed from both existing and new elements that are necessary and practical for multidisciplinary application based on research for organizing and delivering solution options for construction SMEs.

Solutions-Based Models

Solutions-based OSHH research for controlling risk or exposure is currently divided by hazard:

- <u>Chemical risks</u> - silica, solvents, welding fumes, asbestos, and lead.
- <u>Physical risks</u> - ergonomics risks, noise, vibration, heat, and cold.
- <u>Safety risks</u> - working at heights, with energized equipment/machinery, unstable structures.

Various governmental, professional, and industry groups have developed guidance, recommendations, and solutions for use by construction employers. There are a number of ways to organize solutions-based information. We have divided up solution approaches into three models that reflect relative complexity of evaluation and control. This provides a helpful perspective given that the most straightforward low complexity solutions are most likely to be successfully communicated to, and implemented by, SMEs. These three risk approaches are:

- Low complexity - Universal Precautions
- Medium complexity - CBs, subdivided as
    - Task-to-Control
    - Risk–to–Control, and
- High complexity - Expert Driven

<u>Universal Precautions Model</u>

We describe the least complex approach as 'universal precautions' because it involves using a basic control in every situation involving a particular hazard. The term is commonly used in occupational health to describe the use of hand and face personal protective equipment (PPE) in health care with all patients to avoid contacting bloodborne pathogens and other bodily fluids. An example of a common universal precaution in construction is the use of hardhats and steel-toed shoes by all site workers. These precautions are universal because they are implemented on every worksite regardless of work scope or tasks performed. Universal precautions also include other types of measures higher in the control hierarchy, such as machinery guarding, requirements for ladders, prohibited activities, safe traffic routes, equipment maintenance, residual current devices, and requirements for extracted or emission-suppressed tools. The approach is widely used for safety hazards, both in guidance and regulations.

The US Occupational Safety and Health Administration (OSHA) appear to concur with universal precaution terminology in a "Quick Card" for construction PPE. The single-page Quick Card also covers very basic information on selection, use, and care for prescribed PPE. Construction universal precautions listed are PPE for the: eye, face, foot, hand, head, and hearing protection. Simple guidance from the GB Health and Safety Executive (HSE) expands on this model: "The absolutely essential health and safety toolkit for the smaller construction contractor". This sets out checklists for many of construction hazards, presenting short, simplified, and standardized controls by industry sector.

A universal precautions model represents a simple binary approach: when or wherever the hazard is present the same control approach is used. The simplicity of this approach is a major strength. It is the easiest to communicate to employers and employees. It serves to create a baseline of holistic construction rules that every employee should be trained on and aware of, before entering a construction site. It works well with easily recognized hazards. Disadvantages of universal precautions may arise when this approach is applied to complex hazards because the approach may result in overprotection and perceived burden in some cases and under-protection in others. While this may not be a significant issue for low cost controls such as hard hats, it is more challenging for more costly controls. While universal precaution approaches should always be considered, they may not be suitable for complex hazards ranging in severity based on site-specific factors.

Control Banding Model

CB is a medium-complexity approach to evaluation and control of hazards. It involves a structured evaluation of tasks, operations, or work settings. It does not involve quantitative exposure assessment, utilizing operation-specific objective information such as quantities of materials used, exposure properties of substances handled, and nature or duration of tasks. CB originated for use as an alternative approach for controlling chemical exposures. It relies on decision rules derived from prior quantitative studies of various exposure factors. CB allows users to make meaningful inferences about likely exposures and controls needed to reduce them. Thus it represents qualitative risk assessment and risk management approaches. CB groups workplace hazards into four or five stratified risk 'bands', identifying commensurate control measures. Such risk assessment is necessarily generic, so the bands used should apply precautionary assumptions. While OSHH professionals have viewed CB and simplification as a lesser option to quantitative methods, recent application of CB to nanomaterial exposure control has altered that view significantly (Paik *et al.*, 2008; Zalk *et al.*, 2009; NIOSH, 2009). An important application for CB is where uncertainty is high, such as when exposure limits do not exist but substances can be reliably grouped based on similarity to better studied substances. Or when tasks vary in nature, setting and duration, as is often the case in the construction industry.

Development and validation of CB has accelerated internationally, resulting in occupational risk management models being built upon CB principles (Zalk and Nelson, 2008; NIOSH 2009; Zalk *et al.*, 2010a). Most CB 'toolkits' are national initiatives to control SME employees' exposures to chemicals, especially substances without exposure limits. CB strategies have also expanded recently to ergonomics and injury prevention (NIOSH, 2009). CB publications have helped increase control use by providing an evidence-based alternative to quantitative exposure assessment. CB efforts have helped emphasize the need to increase control implementation for SMEs. Although researchers and OSHH practitioners have long worked hard to communicate solutions, even through the late 1990s literature was inconsistent in reporting intervention effectiveness and good practice (Roelofs *et al*., 2003).

Increasing global need has expanded the popular definition of CB as a risk assessment-banding-control model to include "task-to-control" approaches focused on controls needed for specific tasks. Since 2000, national and international collaborations facilitated through the World Health Organisation and the International Labour Organization have been a major driver. These global organisations have provided significant impetus to CB, backing an array of initiatives to prevent work-related injury and illness wherever OSHH expertise is lacking (Fingerhut 2008). US NIOSH highlights construction sector attributes, such as pre-job planning for prevening and managing construction hazards, suggesting that CB approaches could fit well (NIOSH, 2009). Researchers commonly use construction task-based exposure models to evaluate and understand the episodic, highly variable exposures associated with construction activities, and develop work practice and control solutions. While construction is a definitive multidisciplinary activity, such research and solutions tend to not be easily accessible for the worker. OSHH expertise available to SMEs is lacking: meanwhile, regulatory standards and guidance call specific practices and control measures for defined tasks. To date, no set of tools has been developed for construction contractors; although many "task-based" control measures exist and align with CB concepts. To address variability needs, the CB model divides into two sub-categories: task-to-control (T2C) and risk assessment.

Task-to-Control Model

The T2C approach organizes control recommendations by task, rather than by level of risk. PPE may also be recommended for those controls not sufficiently reducing exposures. Standardizing tasks afford multidisciplinary perspectives across the OSHH professions. Although standardizing construction industry tasks is a substantial challenge, there are both common tasks and task components that can meet this expectation. In GB, the Control of Substances Hazardous to Health (COSHH) Regulations were not well understood by SME employers who lacked OSHH expertise, prompting requests for simplified approaches to compliance. This led to 'COSHH essentials', a CB toolkit combining hazards of chemicals or products, and potential exposure, to identify appropriate control measures via 'Control Guidance Sheets' (CGS). Strengths of the T2C model include addressing risks, for a variety of hazards, by identifying established standardized control solutions for individual tasks. Limitations include potential for excessive or insufficient control that standard approaches present. This is particularly true for construction tasks with substantial variability and a heavy reliance on PPE rather than the well-established hierarchy of controls.

Silica and Asbestos. In 2005, new evidence for risk to health at the existing GB silica exposure limit, (0.3 mg/m^3 as an 8-hour Time Weighted Average) emerged (HSE, 2005). This created needs for task-related guidance describing a precautionary degree of good control practice the new limit at 0.1 mg/m^3. This guidance, 'Silica essentials', is identified by industry: here 'COSHH essentials for construction'. 'Silica essentials' is a good example of using 33 construction-related CGS for point-source hazards generated at worksites, with good exposure assessment and controls established. Also, a series of HSE CGS for 'non-licensed' asbestos work applies to lower risk asbestos work in the construction sector. These present the T2C approach in a similar manner as 'Silica essentials', with commensurate approaches to reducing exposures.

This T2C approach to the CB model is effective for SMEs. It gives imperative advice on control measures for defined tasks. It utilizes research findings on exposures associated with tasks along with research on effectiveness of controls. The advice reflects expert consensus, tested by SMEs for usability, acceptability and comprehensibility. Advice is accessed by selecting the appropriate task, such as rock drilling, tile pressing, or abrasive blasting, and downloading the CGS (HSE, 2008b), with ancillary guidance (e.g. appropriate respirator selection; health surveillance for silicosis). Strengths include field application and evaluation, with the 'Silica essentials' CGS being implemented in Southern Africa and Latin America, often adapting the CGS to local conditions and resources. Many have been translated to Spanish and Portuguese (Muianga et al. 2009). In addition, the US Center for Construction Research and Training (CPWR) targets silica control advice directly to workers, in a manner comparable with HSE CGSs. These are in two formats: Construction Solutions Work Practices, and Hazard Alerts (CPWR 2004). Other national studies also identify limitations of relying on respirators alone for silica exposure control in Worksafe Victoria (Australia) and Worksafe BC (Canada). NIOSH has developed a number of task-based "Workplace Solutions" for grinding concrete, tuckpointing, breaking concrete with a jackhammer, and rock drilling.

Ergonomics. Currently the limitation is that there are no true CB toolkits for ergonomics; however, recognizing that a number of approaches and supportive research fit 'T2C' can be seen as a strength. For example, tiling and plastering involve a significant amount of removing and installing materials, overhead and at floor level, with extensive heavy lifting, twisting and carrying. Construction Solutions Work Practices (developed by CPWR) is a 'Construction Solutions' database and an excellent source of information for controlling MSD risks. CPWR offers control solutions in a quasi-CGS format for carrying heavy materials, stooped postures for floor level work, and stressed hand and wrist activities. CPWR solutions for lifting and carrying include using lightweight concrete materials, tool extension devices for work at floor level, and ergonomically designed hand tools to mitigate wrist and arm MSDs 'NIOSH Simple Solutions' for construction ergonomics offers a solutions-based approach for floor level or overhead lifting, and for handling, and hand-intensive work in the form of Tip Sheets (NIOSH, 2007). Acknowledging that sharing worker-developed ergonomic solutions remains limited, the CPWR Construction Solutions database affords an opportunity for posting to share trade-based ergonomic risk reduction solutions. Simplified solutions to reduce MSDs for work at height and floor level can also be found in Ergonomics Checkpoints (ILO, 1996). These might form an appropriate basis for the development of CB ergonomic toolkits, because such practical approaches aim specifically at SMEs internationally and have been updated and improved (Kogi, 2006; Kogi and Caple, 2008). Task-based ergonomics solutions are effective, but 'participatory ergonomics' has the most sustainable effect. 'Participatory methods' means developing solutions, in collaboration with workers and SME managers, that include construction SME strategies (Zalk, 2001; Hignett *et al*., 2005; Kogi and Caple, 2008). These methods led to a measured risk reduction of up to 34% for lifting and carrying materials (de Looze, *et al.* 2001; de Jong and Vink, 2002).

Noise. Noise-induced hearing loss remains common and exposure to high noise levels remains a major issue for construction workers globally (Nelson et al., 2005). Noise and hearing protection belong both to T2C and universal precautions. Although the potential for application of noise reduction and barrier solutions in construction have been around for decades, they are viewed as cost-prohibitive even though there are few data to substantiate this perception (HSE, 1983; Thinksafe, 2007). Both US and GB research indicates that the least expensive and most beneficial noise control practice is to ensure that construction equipment is working and is maintained appropriately (Suter, 2002). However, the construction industry will always have to use hearing protection and its use in US construction worksites is common. But a study of construction workers in their first three years of apprenticeship found measurable hearing loss, even though average noise exposures were measured below 90 dB(A) (Seixas, *et al.,* 2005a). Research has produced substantial information, but correlating elevated noise levels to either trade-based or task-based construction activities is difficult for prioritizing intervention resources (Neitzel, *et al.,* 1999; Seixas, *et al.,* 2003; Seixas, *et al.,* 2005b).

Despite the investment to develop a quantitative task-based solution, University of Washington found that a qualitative evaluation provided a better exposure prediction (Neitzel *et al*., 2009). Recent research by Neitzel focused on methods to increase the actual *use* of abundantly available hearing protection by deploying a semi-quantitative noise level indicator with an alert. The device, worn by a construction worker, lit up at elevated noise levels as a reminder to use hearing protection. This approach created an effective, low-cost individual worker's T2C that fits noise variability and construction SME needs. Wearing the device for just two months ensured significant increases in workers' hearing protection use another two months later. Combining this approach with HSE control solutions can lead to a CB toolkit.

Safety Risks. There is a limitation in that there are no existing CB strategies for 'Safety'. Research is working in this direction, however, and T2C resources to prevent construction injuries continue to appear. A CB-like approach for safety risks, known as Barrier Banding, aims to simplify injury prevention (Zalk, 2006; Zalk, *et al*., 2010b). Rather than 'control measures', safety identifies 'barriers' such as machinery guarding or fall protection to prevent injury. Such barriers are related strongly to safety management systems. The technique involves check-phrases that describe potential accident scenarios, which guide the user towards appropriate precautions against injury (Swuste, 2007, Zalk, 2006). This comprises:

- an innovative look at construction site safety risks
- identifying preventative measures necessary to reduce these risks, and
- having control measures and barriers in place before work starts.

There are a number of solutions-based initiatives that follow this approach, with downloadable information for both construction workers and employers. For example, NIOSH funded CPWR development of an *electronic Library of Construction Occupational Safety and Health* (*eLCOSH*) identifying appropriate risk reduction methods for common construction injuries. In 1997 four stakeholder focus groups began an evaluation of eLCOSH to ensure organization of existing available construction OSHH materials. The website has since grown to 836 documents, with 150 in Spanish. The Construction Solutions database is another internet-based resource from CPWR and NIOSH, referred-to under 'noise', above. It was developed in response to needs of contractors, supervisors and workers in the field who want immediate and accurate information when confronted with problems. The database provides control solutions to construction industry hazards by identifying interventions and control measures demonstrated as effective. Content is created from peer-reviewed literature and other available information. The Construction Solutions database describes T2C measures in practical, end-user terms, organized by hazard and task. The success and value of the database for users will depend on having sufficient coverage for hazards and controls for a given task or trade. It will be launched in phases as various sections are completed. It can support, and encourages, construction user feedback and suggestions for other solutions. This T2C approach for safety solutions is growing with a NIOSH group developing a general Solutions Database for SMEs and other countries working on similar databases (Australia, GB, NL). A task-based prototype for hazards and control measures for "Masonry, Cement, and Plaster" is being tested on focus groups.

Excellent standard implementation guides are offered in Australia through Worksafe Victoria in booklet format. The T2C measures presented for concrete cutting and drilling include a step-by-step approach to address electrical safety, working at heights, barriers necessary for safe work with equipment, and PPE necessary for specific tasks - an expansion of universal precautions. The booklet also provides a checklist for site and equipment safety, and site-specific Job Safety Analysis worksheets. These ensure that prior to starting, comprehensive safety measures are in place, commensurate control measures are implemented, and responsible person identified.

Risk-to-Control Model

A limited selection of CB toolkits are available that could help the construction sector. The Risk-to-Control model utilizes a Risk Level (RL) matrix approach, utilizing qualitative risk assessment techniques. Parameters for defined tasks determine the RL. This RL approach assists in ensuring control measures are sufficient to control risks. Strengths of this approach are that controls are stratified commensurate to risk, it follows the hierarchy of control, and it promotes the potential for substitution.

The strengths and limitations of CB toolkits have been well described (Zalk and Nelson, 2008; ACGIH, 2008; NIOSH, 2009).

While 'COSHH essentials' could be utilized as a construction RL approach, its applications are limited because the focus is the fixed workplace. 'COSHH essentials' has been evaluated for adequacy of its recommended control for tasks requiring solvent-based components (Tischer *et al*., 2003; Tischer *et al*., 2009) and may also be useful for tasks using large quantities of dry materials, such as cement. Recent evaluation of CB against quantitative data sets with solvents and in carpentry-related production show excellent control of exposures below established limits, however a probabilistic model shows CB does not guarantee compliance except for volatile liquids in closed systems and solids with local exhaust ventilation (Tischer *et al*., 2009).

The premier RL approach is 'Stoffenmanager Construction', developed as a pilot to control silica dust exposures for plasterers and tilers (Zalk and Spee, 2008). Its concept is that risk assessment and advice should be based on quantitative exposure assessments wherever possible and modelled calculation should only be applied when there were no exposure data. Stoffenmanager for control of exposure to silica dust has three risk assessment routes, depending on the data available. The program determines which route to use:

- Route 1 uses quantitative exposure data as well as quantitative data about the effectiveness of control measures. It calculates an exposure factor (EF), a reduction factor (RF) and a remaining exposure factor for each task
- Route 2 uses a database of about 4000 building materials and products (developed for the Product Group Information System Arbouw) to locate workplace instruction sheets
- Route 3 deals with products that are not in the database. As in chemical control version of Stoffenmanager, the assessor must enter data.

Factors. 'Stoffenmanager Construction' uses exposure and reduction factors. This is a useful technique to assess the control requirement for a task, through the degree to which an exposure limit is exceeded. According to the European Standard 689, a situation is adequately controlled if the probability of exceeding the limit is 5% or less. Therefore, the 95th percentile (95th %) value of exposure data sets is used as the measure of exposure for the task.

- EF is calculated by dividing the measured exposure by the applicable limit value, whether this limit is health-based or performance-based.
- RF shows to what extent a defined control measure is capable of reducing an exposure. It is calculated by dividing the exposure concentration with no control measure by that with a defined control measure. The RF is also calculated as the 95th % with and without control. Where there is more than one control measure, the RFs for each separate measure are multiplied, eg RF_{LEV} x $RF_{water\ suppression}$
- Divide EF by RF. The remaining value is the EF after control measures have been applied. If the remaining EF is greater than 1, additional control measures are necessary.

In summary, CB utilizes existing researcher data on exposures and control effectiveness. It packages this information into decision rules that allow the selection of controls to be tailored to either specific tasks (T2C) or the most common scenarios and control options (Risk-to-Control or RL Approach). The advantage of CB is that it offers flexibility to accommodate workplace variation and increases likelihood that appropriate controls are used. CB can be considered more complex for employers to use than T2C, therefore reliability can increase when employers have had some basic CB training (Zalk et al., 2010a).. It lends itself to a "competent person" approach, where a trained individual employed by the contractor has the knowledge and authority to implement controls. Disadvantages of CB approaches are the lack of quantitative exposure assessment and direct involvement of an OSHH professional. Therefore, overexposures could occur if controls are not implemented correctly or maintained over time.

Expert-Driven Model

The expert model approach represents the traditional approach whereby an employer utilizes an OSHH professional to evaluate site specific hazards, recommend controls, and manage a safety and health program or system to insure effective implementation. This conventional approach is commonly seen as the 'gold standard'. Strengths are obvious as expert derived prescriptive solutions effectively follow the established hierarchy of controls and are the standard of OSHH professions. This approach provides the highest confidence that hazards are properly evaluated and controlled, especially for highly complex hazards. OSHH professionals are expected to know about research describing exposures and control effectiveness from professional journals and learning about developments via professional conferences. OSHH professional employment by construction employers also helps to institutionalize and integrate OSHH at the organization level and into other key business areas such as design and procurement. The major limitation of this approach is that most SMEs do not employ OSHH professionals as they are expensive and in many parts of the world are rare or non-existent. OSHH professionals also tend to specialize, thus requiring multiple consultants. While the expert-driven model will always be critical for large employers and complex hazards, limitations of this approach have fuelled interest by governments and international organizations in developing CB approaches that provide meaningful alternatives for SMEs.

Framework for a Construction Toolbox Model

Banding of Risk

Over the last few years CB has expanded into wider OSHH fields, beyond substances and chemical products. These are termed 'toolkits': a 'toolbox' may contain several toolkits (NIOSH, 2009). Toolkits use the CB approach of ‘banding’ for assigning the risk of a given hazard to one of several - typically four - levels. Expert models use quantitative risk assessment methods to stratify the risk and define the boundaries between strata. They use data to assign the efficacy of control measures into bands. International collaborations are developing toolkits as 'preventive' measures for OSHH experts and non-experts alike. Toolkits should guide non-professionals, and inform professionals. International CB workshops have promoted CB expansion, research, and publications. They have been a focal point for original applications of simplified risk banding and control approaches for silica exposure, ergonomics, and safety (Zalk and Nelson 2008, NIOSH 2009) and have led to this international collaborative opportunity. Construction industry risk banding requires identifying the right safety solutions across OSHH disciplines to achieve injury and illness prevention. Assigning a band to a project, just as for tasks, is a practical approach to identify and reduce risks relating to work-related accidents and disease.

Construction stakeholders under NIOSH assembled a National Construction Agenda. The agenda provides a framework upon which to develop and promote a construction toolbox, including intermediate goals that build upon task-based control measures, and moves towards pre-job planning, awareness training, competent person training, and CB use. However, interest of US researchers and practitioners in CB construction applications has not led to the development of a toolbox for use by ‘duty holders’ – employers, designers and contractors. A variety of applications, generally falling under the rubric of “task-based” approaches or toolkits, align with CB risk banding concepts. For example, construction researchers recognized early on that “task-based sampling” was most appropriate for understanding and controlling exposures with construction activities (Flanagan, *et al.,* 2006; Flynn and Susi, 2003; Croteau, *et al*., 2002). Multiple opportunities to utilize risk-based CB strategies in the construction industry exist.

Examples. Two major OSHA health standards for construction –for lead (1926.62) and asbestos (1926.1101) - include task-based alternatives that reinforce regulatory applicability.

- The lead standard required that specific precautions be used for identified tasks, ranging from work involving lead based paints (e.g., manual scraping, manual sanding, heat gun applications) to welding, cutting, and torch burning (1926.62(d)(2)).
- The asbestos standard created four classes of work, delineated by risk, with tailored specific precautions for each. It incorporates provisions to treat suspect material as "presumed asbestos-containing materials" as an alternative to bulk analysis testing.

Preliminary versions of an OSHA proposal for silica in construction also included an option for employers to follow specified controls for 8 listed tasks as an alternative to exposure assessment and competent person provisions. Each standard utilizes the concept of a "competent person" capable of identifying hazards, selecting the appropriate control strategy, and with authority to take prompt remedial measures. A GB asbestos decision tool leads to comparable banding decisions – whether or not the job is licensed. If licensed, the full provisions of the Control of Asbestos Regulations 2006 apply. If 'not licensed', there are CGS for common, low risk tasks.

Level of Risk

Safety science has qualitative and semi-quantitative tools to assess risks (Zwaard and Passchier, 1995). Risk is seen as a numeric variable. Simplistically, it combines an adverse effect (or its severity) with a probability of that consequence. Probabilities and consequences are classified into groups and provided with a value. Simple multiplication of values for probability and consequence produce a risk score, used to compare one risk with another for prioritization. An exposure/frequency estimate of hazard and probability of specified consequences for scenarios are compared (Zwaard and Goossens, 1997). Other variations of these tools can include the numbers exposed or the degree to which risk can be controlled via 'relative ranking'. The RL model most often used is divided into four categories, with determination by frequency and severity of hazard. This RL approach has been used recently for an occupational hygiene qualitative risk assessment to control nanoparticle material exposure (Zalk et al. 2009) and as part of a Risk Level Based Management System (RLBMS). The RLBMS is a risk-based occupational risk management model, designed to focus OSHH resources on the highest workplace risks. This model is also auditable, so it fits OSHH management systems and national regulatory oversight (Zalk, *et al.*, 2010a).

The RLBMS model is an appropriate framework for bringing together the control-focused research and solutions-based approaches (Zalk *et al.*, 2010a). RLBMS has shown consistency in integrating multiple solutions across the OSHH professions utilizing an RL delineation of hazards and commensurate controls. Strengths include the use of qualitative risk assessment to achieve regulatory compliance and standardizing a wide variety of tasks. Trades and tasks of the construction industry are more limited, especially for SMEs. RLBMS and solutions-based toolkits offer simple identification and control measures that can fit into a single toolbox. It requires identifying OSHH risks and risk reduction steps for each project phase. The RLBMS approach provides a step-by-step mechanism for creating this toolbox. It takes control solutions from research and good practice, organized within simple project-based and task-based formats. This simple format requires a toolkit structure layered by level of complexity of control solutions. Also necessary is addressing the National Construction Agenda (stakeholders' consensus) to secure pre-job planning to ensure the appropriate level of worksite supervisor training to identify controls matching task-related OSHH risks. This requires a project-specific RL. Therefore, within this framework design proposal we first provide a method to obtain a project specific RL and then present the layered toolkit structure by control levels (CL).

Pre-Job Hazard Analysis (PJHA)

In addressing the need for a project specific RL, Table 1 presents a concept for a PJHA checklist establishing a project-specific band by RL. The table is based on the research-derived hazards inherent to construction trades. Its purpose is to score the hazards within a given construction project. The 'severity checklist' contains common chemical, physical and safety hazards determined independently from specific tasks. The 'probability checklist' determines 'exposure': the project scale, duration, number of workers, overall dustiness, and overall 'potential energy' estimate for project completion. This estimate is based on the concept: higher inherent potential energy yield higher adverse outcome risk from its release. Silica exposures are higher from grinding versus manual breaking; metal fume exposures are higher from torch cutting than mechanical cutting. More energy can lead to more noise; more energy is used in manual handling then with dollies, than utilizing machinery. Higher energy equipment has more severe consequences in the event of electric shock, or heavy equipment failure. Work at height or in trenches implies a potential energy released through a fall. Responses to 'severity' and 'probability' should avoid consideration of control measures.

Insert Table 1

PJHA scores for severity and probability are each individually added. Each score is then found, within a given range, based on a 4 X 4 matrix (Figure 1). Their intersection determines the RL for the construction project and is the first step in this Construction Toolbox design. The RL identifies the level of training and expertise to match the inherent project's risk at the earliest stage (Holmes *et al.*,1999). The RL also indicates the degree of expertise needed for project pre-planning. The next step for the project lead is to identify each of the tasks performed on the jobsite. Securing the appropriate control measures per task is performed using the solutions-based models identified above prior to work commencement. The PJHA RL outcome assists in identifying when control measures for specific tasks require higher expertise then the project lead possesses. As the RL is determined independently from tasks, higher expertise must be obtained for the task or a substitution for a lower risk task approach can be made.

Insert Figure 1

Training and Expertise

The 'toolbox approach' takes into account the 'mentoring relationship' that is (or should be) present in construction trades. An inexperienced apprentice is teamed with an experienced craftsman as mentor, to develop the skills - the knowledge base - of the craft. This process can ensure both competence and an understanding of the craft's OSHH dimensions. Skilled workers are differentiated from apprentices by 'card-carrying' status, certifying 'skill-of-the-craft'. Many European countries and US states require, or are working to require, card-carrying construction trade workers on jobsites, ensuring they possess the skill-of-the-craft to perform their work to codes and regulations. In GB, the Sector Skills Council promotes OSHH skills for construction employees. Defining 'levels of training' in the Construction Toolbox meets this concept. An apprentice may attain 'Basic Craft Skills' with a minimum of training under a mentor, working to skill-based 'Hazard Awareness' by trade at the card-carrying level. In the US, OSHA regulations require higher level training to become 'Competent Persons', to oversee specific activities with inherently higher risk, fitting regulatory requirements discussed above. RL4 work requires 'Expert Training', to assist in understanding and controlling multiple risks.

The key boundary is between RL2 and RL3 - workers will need to be able recognize:

- when work is, and *is not*, within their skill-of-the-craft and
- when they meet the 'Assistance Required' band; needing a certified Competent Person to verify that appropriate control measures are evaluated in place.

Control Level (CL)

With a project specific RL determined, the final step is to assist the jobsite manager in accessing control solutions utilizing a layered toolkit structure. Each layer reflects a CL in this manner:

- CL1 is the universal precautions model. This level deals with the general hazards at the workplace such as tripping and falling as well as head, foot, hand, ear, and body protection. These hazards apply worldwide to everybody at the construction site and everybody at the construction site must have knowledge of these and follow worksite controls identified.
- CL 2 is the T2C model. This level deals with general hazards with basic projects in construction and demolition and include simpler tasks involving hazards such as silica, asbestos, noise, awkward postures, and heavy lifting as well as electrical, machinery, and work at height risks.
- CL 3 is the CB Model. This level requires the collection of simple input parameters to use existing online toolkits such as COSHH Essentials and Stoffenmanager Construction. At this level the construction company can assess hazards and get guidance to control for specific situations.
- CL 4 is specialist advice. This level is for complicated and/or very hazardous situations such as on large asbestos projects, major construction at heights, and extensive concrete demolition, or work involving biohazards, radioactivity, carcinogens, or a vast array of highly hazardous chemicals.

Planning the project prior to initiating work will require the determination of appropriate CLs for each standardized task. Task-related control measures are selected from available options at the specified CL. As indicated above, these are research and solutions-based resources. The advantage of such a layered model is that CL1 and probably CL2 can be filled on a worldwide uniform scale. Knowledge, instruments, factsheets and checklists are all available at these levels. When tasks are at higher levels of risk, such control measures normally need tailoring to project tasks. The CL helps identify the degree of tailoring and type of help necessary for complex situations. Designations CL3 and CL4 mean that workers need help with control measures from a Competent Person or an OSHH specialist. CL3 and CL4 are intentionally aligned in this manner to ensure the provision of effective control measures, and their sustained and correct use.

Discussion

The review and analysis of the solutions-based models presents a wealth of potential tools available across the construction industry. The toolbox framework design presented delivers a banding of project risk that also accomplishes pre-project planning. The primary limitation of the Construction Toolbox is it not being field-tested. The PJHA checklist (Table 1) is a proposal based on expert advice and may require refinement. The scores, and expansion or reduction of the checklist need consideration on national, regional, and cultural bases. The Construction Toolbox will, of course, need evaluation and validation, as a whole and of its parts. The critical issue is the effectiveness and sustainability of control implementation. In theory, the Construction Toolbox approach is well placed to assist the development of mentor-apprentice relationships through standardized OSHH information for construction trades. Also in theory, it would be a tool for appropriate, consistent training of qualified workers, competent persons, the development of OSHH experts in construction, in risk control, and risk management.

In practice, the endpoint of this Construction Toolbox model cannot simply be the identification of an RL, CLs, the production of control advice, and the barriers and control measures in place. Rather, Construction Toolbox use should continue through the project, to assist adaptation as the worksite changes. The correct level of expertise can be identified and risks controlled at all stages. The more common and easily controlled hazards are prioritized as such, represented in the lower RL categories (RL1 and RL2). It is poor practice to control lower risks and milder outcomes before higher risks and more severe outcomes. Therefore, a tool for managers' systematic approach to barriers and controls focuses resources on higher RL events and CL requirements. Focusing expert OSHH professional availability, management-related ‘culpability’ in accident scenarios can also receive appropriate attention.

CB is not - yet - a banding of risk management. Good risk management means reducing high frequency, more severe outcomes from construction hazards.

An important point for the use of CB toolkits is the potential to identify the appropriate control measures in the absence of expertise. At a training level, simplification and uniformity reinforce retention, implementation and the sustainability of prevention. The design of the Construction Toolbox also affords the opportunity to consider these OSHH prevention concepts at the planning, design, and engineering stages of construction projects (Howard 2008). Such ‘prevention through design’ approaches are now available in many countries (CDM 2007, Creaser 2008, Howard 2008, Schulte et al 2008). Some hazards are simply not anticipated. Unnecessary risks may not appear until workers encounter them during the construction process. Therefore, additional risk prevention methods can be found within NIOSH supported research to gather case studies and to provide a conceptual framework for addressing safety and health at the project design phase (Schulte et al. 2008). Banding a project’s RL in pre-project planning therefore offers a complementary prevention through design within the Construction Toolbox framework.

Requirements. The availability and usefulness of a Construction Toolbox will require:

- a web-based format for standardized tasks and related CLs that is continually updated,
- free and readily accessible control guidance that is acceptable, comprehensible and usable,
- free and readily available web access to existing solutions-based resources, and
- a web-based format to share successes and lessons learned by both task and trade.

Sharing control solutions and lessons learned, e.g. post on website, require CGSs that include:

- checklists for control measures and barriers, and
- a 'Work-site Hazard Analysis' worksheet.

These require testing of formats to optimise, for users, ‘drill-down’ for access to control advice based on tasks that they recognise. Tasks should include variables such as those in Table 1, e.g. duration, other workers' proximity, the variety of controls that might be available. ‘Drill-downs’ produce CGSs that include task summary and generic control measures and/or barriers, or specific CGSs as necessary for tasks. Web-based ‘drill-down’ actively linked to the Construction Toolbox have potential for currency, updating and real-time translations. This would enhance the risk management aspect, communicate hazard-to-control to the worker, and offer field-based advice to others in a participatory format. The PJHA can also be similarly useful. For SMEs, each question can be linked to a brief explanation and additional resources links as they determine the CL, task-by-task. The SME manager can begin to consider all opportunities for hazard or task substitution, and selecting task parameters to reduce the overall expertise required. Users and experts can score online resources such as CGSs and CL-based solutions for utility, simplicity, and effectiveness as feedback, for evaluation. SMEs can also get Construction Toolboxes on CD by trade, having ‘drill-down’ format, but no web-based benefits.

In seeking to address these issues, the intent is to remain global in scope. However, many of the current control solutions are skewed toward a few countries. There are often national research gaps, so international research and literature requires locating and consideration. In economically developing countries the number of OSHH professionals and technicians need substantial growth. The Construction Toolbox can become a foundation for training OSHH experts and technicians in construction in university programs, and spreading expertise through train-the-trainer campaigns. Developed countries can also use such campaigns, with exchange of successful control information where language barriers exist. The process can work best internationally when key aspects of the CL approaches in the CGS are communicated largely through pictorial formats, to minimise the need for translation and standardizing the control expectations. For example, the HSE is developing a short series of simple icons as an ‘employee checklist’. But this whole context is reliant on a Construction Toolbox existence, acceptance, dissemination, and use. Therefore, the authors would advocate that ILO or WHO set up an international working group to collect and order existing information and to make this readily available (e.g., internet or booklets). In this manner, as experts are lacking in many developing countries, an initial goal to 'pick the low-hanging fruit' would be a solid step in right direction. If all countries implemented simple, practical strategies to prevent accidents, it would be possible to eliminate 83% of safety-related deaths and 74% of accidents annually (ILO, 2005b).

Conclusion

A constant throughout this discussion is recognition that workers in the construction industry are involved in a dangerous trade. Construction work-related risks are well understood, but it remains a leader for raised injury, illness and fatality rates; and associated costs to business, society and families. It is unconscionable that construction remains hazardous, while resources over decades - statistics, causal factors, and control measures to reduce risk - are known to OSHH professionals. Construction Toolbox development seeks to change the perception that work-related risks in this sector are just safety-related and inevitable; rather it emphasizes that chemical and physical exposures abound and are preventable. The concept is a comprehensive tool for the construction industry, to assess and control occupational risks that currently are segmented between OSHH professions. The Construction Toolbox presents a format to harness multiple solutions-based national programs and publications for controlling construction-related risks across the OSHH professions. CB and Barrier Banding have been united in this RLBMS format using simplified risk assessment and risk management strategies. Multiple OSHH professional expertise unite in this framework to organize, communicate, and implement risk reduction programs at a construction jobsite. Our intent was to propose a simplified risk banding approach for the SMEs that employ over 80% of the world's construction workers.

This occupational risk management toolbox strategy:

- uses a qualitative risk assessment approach to determine an RL 'band' for a given project,
- identifies the appropriate level of training to oversee the work, and
- enables identification and implementation of suitable control measures for safe working.

Such a strategy has long been sought, but never presented in this format. Critical elements of the work remain to be done on the research side are:

- the validation and verification of this toolbox approach,
- implementation and further evaluation of the PJHA checklist,
- practicality of integrating enforcement and national regulatory compliance,
- a movement back toward solutions-based practical, field research, and
- multidisciplinary collaborations at local, national, and international levels.

To appropriately develop the Construction Toolbox components, the needs in practice are:

- development of centralized databases at the T2C level expanded across the professions,
- creation of training packages for SMEs and train-the-trainer packages for experts,
- scaling to the Construction Toolbox model to economically developing countries, and
- sharing of successes and limitations as well as field-based feedback and improvement.

Further, the creation of the necessary centralized web-based system to unify an international implementation will require funding, development, and maintenance ensuring the Construction Toolbox availability to the world's construction SMEs. Delivering such an essential product to SME managers is the first, but most important, step. However, without further analysis and field implementation it will remain just another publication seeking to reduce the constant stream of work-related injuries and illnesses, an abhorrent mark on the construction industry worldwide.

Construction Solutions-Based Internet Resources

HSE Construction Silica Essentials
OSHA Construction Industry assistance
University of Washington silica solutions
University of Washington noise hearing loss, construction
NIOSH Construction Health and Safety solutions
NIOSH Respirator resource
The Center for Construction Research and Training (CPWR)
CPWR Simple Ergonomic Solutions for Construction
CPWR Construction Solutions
eLCOSH
Worksafe British Columbia, Canada
Worksafe Victoria, Australia

Acknowledgements

Tamara Onos for her efforts in support of Stoffenmanager Construction. This work, in part, was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, LLNL-JRNL-####.

References

ACGIH (2008). Control Banding: Issues and Opportunities. ACGIH Publishing, Cincinnati.

Ale B, Bellamy L, Baksteen H, Damen M, Goossens L, Hale A, et al. (2008). Accidents in the construction industry in the Netherlands: an analysis of accident reports using storybuilder. Reliab engin and syst safety. 93;1523-1533.

Bentley T, Hide D, Tappin D, et al. (2006). Investigating risk factors for slips, trips and falls in New Zealand residential construction using incident-centred and incident-independent techniques. Ergon. 49: 62-77.

BLS (2007). Bureau of Labor Statistics occupational injury, illness, and fatality data http://www.bls.gov/news.release/cfoi.toc.htm

CDM (2007). Great Britain regulatory framework in Construction (Design and Management) Regulations, 6 April 2007. http://www.hse.gov.uk/construction/cdm.htm

Chi CF, Chang TC, Ting HI. (2005). Accident patterns and prevention measures for fatal occupational falls in the construction industry. Appl Ergon. 36(4):391-400.

Collis E. Greenwood M. (1921). The health of the industrial worker. Churchill, London.

CPWR (2004). Silica Hazard Alert http://www.cpwr.com/pdfs/pubs/hazard_alerts/KFsilica.pdf

Creaser W (2008). Prevention through design (PtD) safe design from an Australian perspective. J Saf Res. 39(2):131-134.

Croteau G., S. Guffey, M. Flanagan, and N. Seixas (2002). The Effect of Local Exhaust Ventilation Controls on Dust Exposures During Masonry Activities. AIHA Journal 63:458–467.

De Jong AM, P Vink (2002). Participatory ergonomics applied in installation work. Appl Ergon 33(4):39-46.

De Looze MP, IJM Urlings, P Vink, et al (2001). Towards successful physical stress reducing products: an evaluation of seven cases. Appl Ergon 32(5):525-534.

Fingerhut M (2008). Global qualitative risk management (control banding) activities. Industr Health 46:305-307.

Flanagan M.E., N. Seixas, M. Majar, J. Camp, M. Morgan (2003). Silica Dust Exposures During Selected Construction Activities. AIHA Journal 64:319–328.

Flanagan M.E., N. Seixas, P. Becker, B. Takacs, J. Camp (2006). Silica Exposure on Construction Sites: Results of an Exposure Monitoring Data Compilation Project. J Occup Environ Hyg, 3(3):144-52.

Flynn, M. R. and P. Susi (2003). "Engineering controls for selected silica and dust exposures in the construction industry--a review." Appl Occup Environ Hyg 18(4): 268-77.

Geraedts R, Wamelink H. (2008). Dutch status report: voluntary arrangements for collaborative working in the construction sector. EU Tendor No ENTR/07/008.

Haslem FA Hide SA et al (2005). Contributing factors in construction accidents. Appl Ergon. 36:27-31.

Hignett S, JR Wilson, W Morris (2005). Finding ergonomic solutions – participatory approaches. Occup Med. 55:200-207.

Holmes N, Lingard H, Yesilyurt Z, De Munk F (1999). An exploratory study of meanings of risk control for long term and acute effect occupational health and safety risks in small business construction firms. J Safety Res. 30(4):251-261.
Howard J (2008). Prevention through design – introduction. J Saf Res. 39(2):113.
HSE (1993). 100 Practical applications of noise reduction methods. United Kingdom Health and Safety Executive (HSE). HMSO. London.
HSE (2005). Health and Safety Commission paper HSC/05/55 United Kingdom Health and Safety Executive (HSE). HMSO. London, http://www.hse.gov.uk/aboutus/meetings/hscarchive/2005/050405/c55.pdf.
HSE (2007). Control of Substances Hazardous to Health (COSHH) Essentials guidance publications, United Kingdom HSE, http://www.hse.gov.uk/pubns/guidance/index.htm.
HSE (2008a). Health and Safety Statistics 2007/8, United Kingdom HSE, http://www.hse.gov.uk/statistics/overall/hssh0708.pdf
HSE (2008b). Control of Substances Hazardous to Health (COSHH) Essentials guidance publications. United Kingdom United Kingdom HSE.
ILO (1996). Ergonomic Checkpoints: Practical and easy-to-implement solutions for improving safety, health and working condition. ISBN 92-2-109442-1, ILO: Geneva, 1996
ILO (2005a). Facts on Safety at Work. International Labour Office, Geneva http://www.ilo.org/global/about-the-ilo/media_and_public_information/Factsheets/lang—en/docnamer—WCMS_067574/index.htm.
ILO (2005b). Introductory Report; Decent Work - Safe Work. XVIIth World Congress on Safety and Health at Work. Orlando, Geneva, International Labour Office, Geneva http://www.ilo.org/public/english/protection/safework/wdcongrs17/intrep.pdf.
ISSA (2009). The Declaration of Brussels, International Social Security Association, section non prevention in construction, Belgium 25 November 2009. http://www.issa.int/prevention-construction
Kellogg P. (1909). The Pittsburgh Survey. Charities Publications Committee, New York.
Kreuter MW, Bernhardt JM (2009). Reframing the dissemination challenge: a marketing and distribution perspective. Am J Public Health. 99(12):2123-2127.
Kogi, K. (2006). Advances in participatory occupational health aimed at good practices in small enterprises and the informal sector. Ind. Health, 44:31-34.
Kogi K, Caple D (2008). Developing ergonomic checkpoints for facilitating practical improvements in small-scale workplaces. SY20-03. *XVIII World Congress on Safety and Health at Work*, Seoul, Korea.
Kristenson TS (2005). Intervention studies in occupational epidemiology. Occup Environ Med. 62:205-10.
LI (2008). Projectrapportage kwarts in de bouw (project report quartz in Construction, in Dutch). Labor inspectorate, the Hague, the Netherlands. http://docs.minszw.nl/pdf//38/2008/38_2008_6_18355.pdf
Lingard H, Holmes N (2001). Understandings of occupational health and safety risk control in small business construction firms: barriers to implementing technological controls. Const Manag & Econ, 19:217-226.
Lumens M, Spee T (2001). Determinants of exposure to respirable quartz dust in the construction industry. Ann Occup Hyg 45(7):585-595.
Malchaire JB (2004). The SOBANE risk management strategy and Deparis method for the participatory screening of risks. Int Arch Occup Environ Health 77: 443-450.
Murie F (2007), Building safety – an international perspective. Int J Occup Environ Health 13 :5-11.
Neitzel R, NS Seixas, J Camp, M Yost (1999). An assessment of occupational noise exposures in four construction trades. Am Ind Hyg Assoc J. 60:807-817
Neitzel R, D William, L Sheppard, et al (2009). Comparison of perceived and quantitative measure of occupational noise exposure. Ann Occup Hyg 53(1):41-54.
Nelson DI, Nelson RY, Concha-Barrientos M, Fingerhut M (2005). The global burden of occupational noise-induced hearing loss. Am J Ind Med 48: 446-458.
NIOSH (2007). Simple Solutions: Ergonomics for Construction Workers NIOSH Publication No. 2007-122. http://www.cdc.gov/niosh/docs/2007-122/floor.html.
NIOSH (2008). National Occupational Research Agenda: National Construction Agenda for Occupational Safety and Health Research and Practice in the U.S. Construction Sector. Developed by NORA Construction Sector Council, Oct. 27, http://www.cdc.gov/niosh/nora/comment/agendas/construction/pdfs/ConstOct2008.pdf
NIOSH (2009). Qualitative risk characterization and management of occupational hazards: Control Banding (CB); a literature review and critical analysis. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2009–152.

Onos T, Hoonakker PLT, Spee T (2003) Nulmeting in het kader van het arboconvenant kwarts in de afbouwsector. (baseline survey for the working conditions agreement on quartz in the finishing sector, in Dutch) Arbouw, Amsterdam.
Paik S, Zalk DM, Swuste P (2008). Application of a pilot control banding tool for risk level assessment and control of nanoparticle exposures. Ann Occup Hyg 52 (6): 419-428.
Roelofs CR Barbeau EM, et al (2003). Prevention strategies in Industrial Hygiene: a critical literature review. AIHA Journal 64:62-67
Schulte, P. Rinehart, R. Okun A. et al (2008). National Prevention through Design (PtD) Initiative. Journal of Safety Research. 39(2):115-121.
Seixas NS, L Sheppard, R Neitzel (2003). Comparison of task-based estimates with full-shift measurements of noise exposures. Am Ind Hyg Assoc J. 64:823-829.
Seixas NS, B Goldman, L Sheppard, R Neitzel, et al (2005a). Prospective noise induced changes to hearing among construction industry apprentices. Occup Environ Med 62:309-317.
Seixas NS, R Neitzel, L Sheppard, B Goldman (2005b). Alternative metrics for noise exposure among construction workers. Ann Occup Hyg 49(6):493-502.
Staatscourant (2001) Staatscourant (Government Gazette in dutch) 19 Oct. 2001, p 14. http://www.staatscourant.nl/
Suter AH (2002). Construction noise: exposure, effects, and the potential for remediation; a review and analysis. Am Ind Hyg Assoc J. 63:768-789
Swuste P. (2007). Qualitative methods for occupational risk prevention strategies in safety, or control banding – Safety. Saf Scienc Monitor 11(3):1-7.
Swuste P. (2008). You will only see it, if you understand it', or occupational risk prevention from a management perspective. Hum Fact and Ergon in Manuf, 18:438-53.
Thienen G van, Spee T (2008). Health effect of construction materials and product. J Applied Occup Sci. 1:2-23.
Thinksafe (2007). Noise management in the construction industry: a practical approach. Worksafe. http://www.docep.wa.gov.au/Worksafe/Content/Safety_Topics/Noise/Further_information/Noise_management_in_the_constr.html
Tischer, M., S. Bredendiek-Kamper, and U. Poppek (2003). Evaluation of the HSE COSHH Essentials exposure predictive model on the basis of BAuA field studies and existing substances exposure data. *Ann. Occup. Hyg.* 47(7):557-69.
Tjoe Nij E, Heederik D (2005). Risk assessment of silicosis and lung cancer among construction workers exposed to repsirable quartz. Scand J Work Environ Health. 31(2):49-56.
USCB (2004). Country Business Patterns (NAICS), U.S. Census Bureau. http://censtat.census.gov/cgi-bin/cbpnaic/cbpdetl.pl
Vedder J, Carey E (2005). A multi-level systems approach for the development of tools, equipment and work processes for the construction industry. Appl Ergon, 36(4):471-80.
Waehrer GM. XS Dong, T Miller, et al (2007). Costs of Occupational Injuries in Construction in the United States. Accid Anal Prev. 39(6): 1258–1266.
Wagner GR (1995). The inexcusable persistence of silicosis. Am Public Health Assoc. 85(10):1346-1347.
Waterson A. (2007). Global construction health and safety – what works, what does not, and why? Int J Occup Environ Health. 13(1):1-4.
Weinstein MG, Hecker SF, et al (2007). A roadmap to diffuse ergonomic innovations in the construction industry. Int J Occup Environ Health 13:46-55.
Zalk DM (2001). Grassroots ergonomics: initiating an ergonomics program utilising participatory techniques. Ann Occup Hyg 45(4):283-289.
Zalk DM (2006). Practical prevention in safety; from control banding to barrier banding. *Proceedings* 17(5), *International Working on Safety Conference*, 15 September 2006 Eemhof, The Netherlands.
Zalk DM, Nelson DI (2008). History and evolution of control banding: a review. J Occup Environ Hyg. 5(5):330-46
Zalk DM, T Spee (2008) Barrier banding and the construction toolbox. *Proceedings* SY20-04*, XVII World Congress on Safety and Health at Work*, 1 July 2008 Seoul, South Korea.
Zalk DM, Paik S, Swuste P (2009). Evaluating the Control Banding Nanotool, a qualitative risk assessment approach for controlling nanomaterial exposure. J Nanopart Research. 11(7):1685-1704.
Zalk DM, Kamerzell R, Paik S, Kapp J, Harrington D, Swuste P. (2010a). Risk level based management system: a control banding model for occupational health and safety risk management in a highly regulated environment. Industrial Health, 48(1):18-28.
Zalk DM, Swuste P, Hale A (2010b). Barrier banding: a concept for safety solutions utilizing control banding principles. Submitted to Safety Science, May 2010.

Table 1: Pre-Job Hazard Analysis Checklist Concept

SEVERITY – Answer reflects hazard potential *without* controls in place (Yes = 4 points each)

Chemical

Is there a possibility that asbestos-containing materials will be encountered?	Yes ☐	No ☐
Is there a possibility that lead-containing materials will be encountered?	Yes ☐	No ☐
Will there be jack hammering, roto-hammering or similar concrete work	Yes ☐	No ☐
Will there be breaking or cutting of tiles, masonry or other silica dust work	Yes ☐	No ☐
Will the job involve welding, soldering, or torch cutting?	Yes ☐	No ☐
Will there be engines running on the worksite?	Yes ☐	No ☐
Will work involve chemicals, solvents, painting, brazing or grit blasting?	Yes ☐	No ☐
Will work be within vaults, manholes, trenches, or tanks >4 feet deep?	Yes ☐	No ☐
Will the workers require personal protective clothing?	Yes ☐	No ☐
Will the job involve materials or processes requiring respiratory protection?	Yes ☐	No ☐

Physical

Is there a potential for manual material-handling of items over 40 pounds?	Yes ☐	No ☐
Is there a potential for repetitive tasks for more than 30 minutes a workshift?	Yes ☐	No ☐
Is there a potential for repetitive transfer of materials less than 40 pounds?	Yes ☐	No ☐
Will workers be exposed to elevated noise levels on this job?	Yes ☐	No ☐
Is there high (e.g. jackhammer) or low vibration (e.g. manned cab vehicles) activity?	Yes ☐	No ☐

Safety

Will work be performed on or near energized equipment, lines, or circuits?	Yes ☐	No ☐
Will there be overhead power lines or potential underground or hidden utilities?	Yes ☐	No ☐
Will workers be working above 6 feet from ground level?	Yes ☐	No ☐
Will scaffolding or ladders be used and worker access be provided?	Yes ☐	No ☐
Will there be work cutting, grinding, or breaking of concrete or masonry?	Yes ☐	No ☐
Will the job involve steel and/or scaffolding erection?	Yes ☐	No ☐
Will floor, wall, and/or roof openings be created during this job?	Yes ☐	No ☐
Will crane(s), forklift(s), manlift(s), or other lifting equipment be used?	Yes ☐	No ☐
Will there be excavation or trenching in excess of 4 feet?	Yes ☐	No ☐
Will the subcontractor be using motor vehicles or heavy equipment on-site?	Yes ☐	No ☐

PROBABILITY (Highest = 20 pts, Mid = 10 pts, Lower = 5 pts, Lowest = 0 pts)

Number of workers on the jobsite?	More than 10 ☐	6 - 10 ☐	3 - 5 ☐	1 - 2 ☐
Length of project in 8-hour days?	10 or more ☐	6 - 9 ☐	2 - 5 ☐	1 ☐
Dustiness on the jobsite (no controls in place).	High (clouds) ☐	Moderate (visible) ☐	Low (puff) ☐	None ☐
Fuel-, electrical-, & manual- based energy on jobsite?	High ☐	Moderate ☐	Low ☐	None ☐
Will the work be performed indoors?	Mostly ☐	Sometimes ☐	Rarely ☐	None ☐

Figure 1. Risk level (RL) Matrix for Determination of Jobsite Training Requirements.

Probability Score

Severity score		Extremely Unlikely (0-25)	Less Likely (26-50)	Likely (51-75)	Probable (76-100)
	Very High (76-100)	RL 3	RL 3	RL 4	RL 4
	High (51-75)	RL 2	RL 2	RL 3	RL 4
	Medium (26-50)	RL 1	RL 1	RL 2	RL 3
	Low (0-25)	RL 1	RL 1	RL 1	RL 2

Training requirements by risk level:

RL 4: Expert required on jobsite
RL 3: Competent person required on jobsite
RL 2: Hazard awareness expertise required on jobsite
RL 1: Basic craft skills sufficient on jobsite